ELEMENTS of RADIO

VOLUME I

MARCUS · HORTON

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ELEMENTS OF
RADIO

Volume I

ELEMENTS OF RADIO

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and

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VOLUME I

Prepared at the request of the War Department and the U. S. Office of Education in conformance with official pre-induction training course outline No. 201

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Dedication

To the thousands of men and women who patiently and painstakingly helped answer the myriad of questions that swirled through our heads we gratefully dedicate this book.

Some of them we had the pleasure of meeting in person. Others we knew only through the anonymity of a name on a book or a signature to a magazine article. But through speech or through the printed word, each of them helped pass on our common heritage, our civilization.

We fondly hope that in some slight measure we do likewise and thus repay, in small part, the debt we owe to our teachers.

Abraham Marcus
William Marcus

The establishment of pre-induction training in civilian schools is an historic event. The Pre-Induction Training Section of the Civilian Personnel Division, Headquarters, Services of Supply, has been established as the central coordinating agency of the War Department to simplify and facilitate arrangements for the appropriate training of individuals prior to their entrance into military service. The outlines herewith presented have been prepared to serve all three divisions of the Army—the Army Air Forces, the Ground Forces, and the Services of Supply. The prospect of effective collaboration between the educational and armed forces of the Nation is a healthy symbol of a vigilant democracy in action.

Robert P. Patterson
Under Secretary of War

Preface

A generation of Americans has grown up since the advent of radio broadcasting. We have more radio sets, per capita, than any other nation in the world. Yet, our country at war must set up an extensive training program to teach our men and women an understanding of radio. How are we to account for this?

Years of experimentation with methods of teaching radio to beginners have led the authors to the conclusion that the fault lies with our pedagogy. We require the student to learn a mass of laws and principles of electricity before teaching him radio. Some of the students may survive this ordeal, but most of them quickly lose interest or else merely memorize these abstract concepts which have no meaning or reality for them.

Our conclusions led in another direction. Most of us think in terms of our environment. Thus the student's contact with radio is, primarily, with his receiver at home. Accordingly, he should learn first how the radio receiver operates. So important is this that this first volume is devoted entirely to the receiver.

Of course, it would be absurd to attempt to explain to the beginner the operation of the modern superheterodyne receiver at the very beginning of the book. The simple crystal receiver is chosen as embodying all the basic principles of any receiver.

To insure a complete understanding of this simple receiver, the device of the spiral is adopted in presenting the subject matter. Thus at the first cycle an extremely elementary explanation of the radio is presented—tuning, detection, and reproduction. The next turn around covers the same ground but at a slightly higher level. And so on through the various cycles.

But at each level the complete radio receiver is presented. By this means the student's interest is maintained. Also, at each stage, set construction is presented so that the student can see the result of the theoretical concepts of that stage in concrete form.

Having mastered an understanding of the simple crystal receiver, the student is led on to more advanced sets by being confronted with problems he must solve. Thus, the drawbacks of the crystal detector lead to the development of the vacuum-tube detector. To eliminate the nuisance of headphones requires the audio-frequency amplifier. Our search for sensitivity leads us to the radio-frequency amplifier. And so on. Note that this is how the science of radio actually developed.

Another "must" is the elimination, as far as possible, of all formulas and mathematics. Too often a formula is substituted for an explanation. We must remember that what is perfectly clear to the engineer may not be so clear to the student. Thus this first volume does not contain a single formula.

The second volume of the series is devoted to electrical theory, transmitters, and more advanced aspects of radio. It is hoped that the student will be sufficiently enthusiastic and curious to continue beyond the first volume. But even if he is not, it must be remembered that each volume is a complete unit in itself.

Teaching Devices

To make the textbook a useful tool of instruction, several devices approved by most progressive teachers are included:

1. *Problems* are set up as questions at the beginning of each chapter.
2. Paragraphs are numbered and introduced by *black-face captions.*
3. A *glossary* appears at the end of each chapter.
4. A set of *questions* and *problems* accompanies each chapter.
5. A complete program of classroom *demonstrations* is provided at the end of the text.
6. Useful *tables of data* are grouped in the *Appendix.*
7. The *drawings* are large and more than usually profuse. They are definitely directed toward explanation—not for adornment.
8. A *Table of Contents* may be used as a guide to weekly planning of work.
9. A detailed index for easy reference will be found at the end of the book.

The Time Allotment

Experience with classes has shown that each volume may serve for about one semester when one period per day, five times a week is the schedule. For more intensive work in the war course program, the period may be cut down to a few weeks.

Methods and Equipment

It is recommended that all principles be introduced and investigated as a problem or difficulty; that the principles be demonstrated by the teacher, and that one period or more per week be given to practical wiring, testing, soldering, and measurement by the students in the laboratory. The facilities of the school will determine the amount of individual laboratory work that can be done. But it is believed that any instructor with the ordinary equipment in physics and with the addition of the parts salvaged from one or more radio sets can carry out most of the demonstrations listed in the back of the book.

The Authors

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Volume I

CHAPTER I

History of Communication

Problem: *How has man improved his means of communication since time began?*

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1. Sound Signals

Ever since man could make a sound, he has attempted to transmit messages over ever-increasing distances. A shout may have been the first "long-distance transmission." Man soon learned that greater distances could be spanned by beating with a club on a hollow tree and, even today, a fairly efficient and effective system of drum-beat communication exists among primitive tribes.

2. Sight Signals

Another ancient method of message transmission involves the sense of sight. From hand-waving men progressed, thousands of years ago, to the waving of flags, the use of puffs of smoke, of fires and lanterns, of the heliograph—a device whereby sunlight is reflected by mirrors and flashed over considerable distances.

All of the above methods of communication suffer from one common fault. They are useful only over comparatively short distances, a few miles at best.

3. The Telegraph

Nevertheless, it was not until the nineteenth century that better means of communication were devised.

In 1832, Samuel F. B. Morse invented the electric telegraph. By sending an electrical impulse along a wire, he operated an electromagnet at the end of the line. This electromagnet attracted a bar of iron, causing an audible click. By means of a code these clicks were translated into letters and words.

This was a big step forward. No longer was man bound by the limits of sight and hearing. Wires could be strung for many miles and the electrical impulses could be sent through them at the incredible speed of nearly 186,000 miles per second! In 1866, the first message was sent from America to Europe by means of a telegraph cable beneath the Atlantic Ocean.

4. The Telephone

In 1875 another stride forward was taken when ALEXANDER GRAHAM BELL invented the telephone. Now sound could be converted into electricity at the transmitting end of the line, sent through wires at the same tremendous speed as in the telegraph, and reconverted into sound at the receiving end of the line. Thus the very spoken word was sent by wire over hundreds and thousands of miles!

5. Wireless Telegraph—Radio

Marvelous advances though they were, the telephone and telegraph fell short of meeting the demands which our ever-expanding civilization put upon them. Wires could not be strung everywhere. Explorers and ships at sea were cut off from communication with home and each other. The balloon, and later the airplane, required some means of communication that did not entail stringing wires from sender to receiver. In short, a wireless telegraph and a wireless telephone were clearly needed.

Like all great inventions, neither the wireless telegraph nor the wireless telephone (or radio, as we now call them both) was the product of any one man's activity. Many men from many lands each contributed their shares before the radio came into being.

Nearly a quarter of a century before the first radio wave was produced intentionally, an English scientist, JAMES CLERK MAXWELL, by means of an elaborate mathematical formula, proved the possibility of producing the radio wave. This was in 1864. His contribution was the theory of electromagnetic waves.

6. Radio Communication

In 1888, HEINRICH RUDOLF HERTZ, a young German in Frankfort, succeeded in transmitting the first radio wave across a room and picking up this wave signal on an extremely crude type of receiver.

Then followed a half-dozen years of activity during which a large number of scientists each contributed some addition or improvement. These experiments finally led to the wireless telegraph, the first practical radio system. This was invented by Guglielmo Marconi, a young Italian, in 1895. With his system, Marconi was able to send and receive messages for several miles without any intervening wires. In 1901, Marconi succeeded in spanning the Atlantic Ocean.

Here, indeed, was the way to the solution of the needs of the twentieth century—a system of communication over long distances with no need for interconnecting wires.

SUMMARY

In this chapter we have learned that man has improved his means of communication gradually. The probable steps in the progress have been successively, sound, light, electrical signals on wires, and finally signals sent and received through space by radio.

QUESTIONS AND PROBLEMS

1. What were the shortcomings of primitive means of communications?

2. What needs of daily life made wired systems of electrical communication inadequate?

3. Who first proved mathematically the possibility of producing the radio wave? When? What is the name of his theory?

4. Who first produced an elementary radio transmitter and receiver? When?

5. Who invented the first practical radio system? When? What was this system called?

CHAPTER 2

Wave Motion

Problem: *What is a wave?*

Radio communication, we are told, travels in *waves*. We must therefore try to understand what a wave is.

7. Water Waves

If you drop a pebble into a pond of still water, *ripples* or *waves* are created, and these travel away from the splash in ever-widening circles.

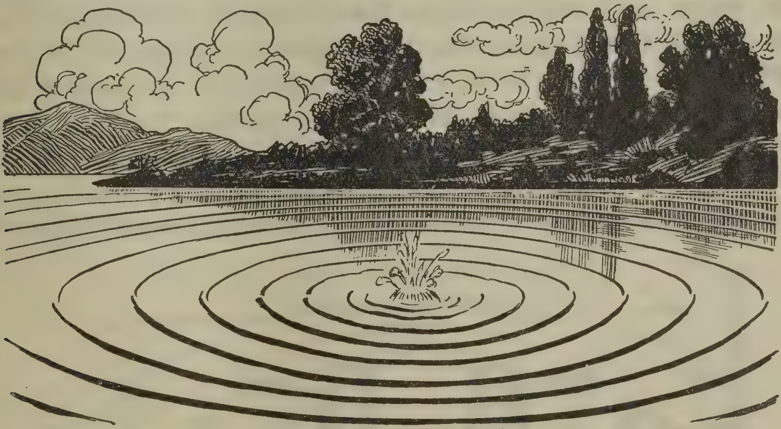

Figure 1. Ripples caused by throwing a stone into a still pond. These ripples travel in ever-widening circles from the point of disturbance.

If you examine these waves, you can see how they are formed and how they travel. The falling pebble, when it strikes the water, pushes some water away from its path, forming a sort of cavity or hollow in the pond. The displaced water is piled up all around the cavity and is forced above the normal level of the pond in a circular wall.

The weight of the water causes this circular wall to collapse, to fall—and when it falls it goes past and below the original level of the pond. This falling water, like the falling pebble, in turn displaces some more water, causing another circular wall to be built up a little distance away from the original cavity. This rising and falling continues on and on. The building up and collapsing of the walls of water causes the wave to travel away from the original hollow made by the pebble. Because of the resistance of the water, each wall is a little lower than the one before it and when it falls it descends a little less below the surface of the pond.

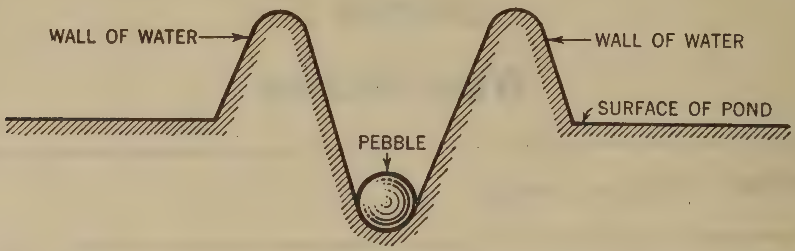

Figure 2. Sectional view of the pond showing the crater and wall of water formed by the falling pebble.

Place a small piece of cork on the surface of the pond a little distance away from where you drop the pebble. As the ripples reach the cork, it bobs up and down but does not travel on with the wave. This shows how each *particle* of water moves up and down but does not travel across the pond as the wave does.

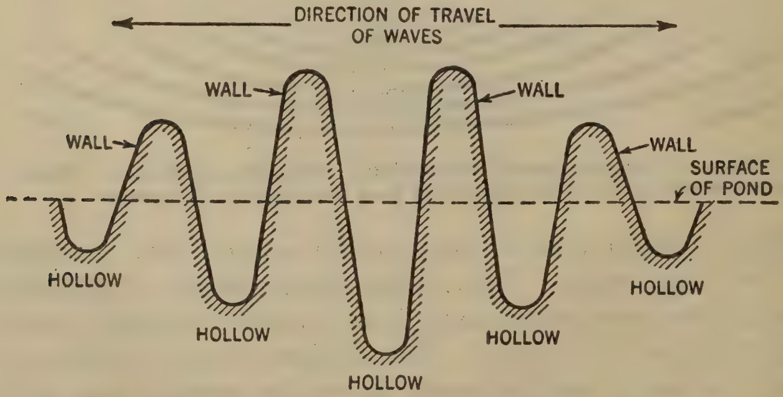

Figure 3. Sectional view of the pond showing the series of circular walls and hollows formed by the falling pebble.

8. What Really Travels?

You can better understand this behavior, perhaps, if you set up a row of dominoes. Tip the first one against the one alongside it. It will push its neighbor against the next one and so on. The *motion* (or wave) will pass through the whole row, but each domino will travel only a short distance.

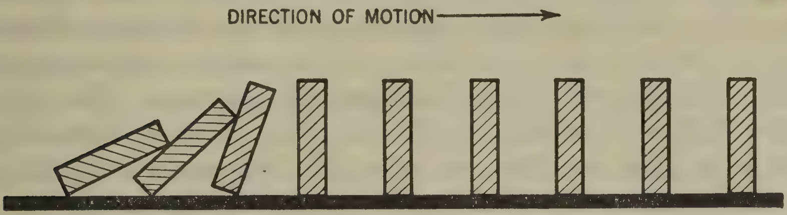

Figure 4. A row of dominoes illustrating wave motion.

It is the *energy* caused by the weight of the falling domino that travels, not the dominoes. Similarly, in the case of the water wave, the particles of water do not travel across the pond; it is the energy alone that does the traveling.

Obtain a fairly heavy rope about fifteen feet long. Fasten one end to a post. Now move the free end up and down. The rope seems to travel towards the post. But the rope itself is not traveling. You can see that because the free end is no nearer the post now than before. Each particle of rope is moving merely up and down. It is the *energy* or *wave* that is traveling through the rope from the end in your hand to the end fixed to the post.

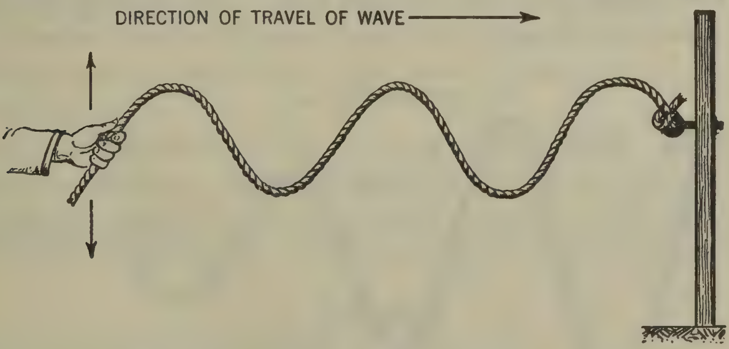
DIRECTION OF TRAVEL OF WAVE

Figure 5. Illustrating wave motion with a rope.

In these examples, the water, the dominoes, and the rope are each called the *medium*. The particles of the medium move a very short distance. *It is the energy or motion traveling through the medium from particle to particle that we call the wave.*

9. Wavelengths

Let us look more closely at the ripples in the pond. Recall that the pebble forms a hollow in the pond and builds up a wall of water next to that hollow; when this wall falls it makes a hollow next to it; and so on. Note that the walls and hollows alternate; that is, first there is a wall, then a hollow, then a wall, and so on. The top of the wall is called the *crest* of the wave. The bottom of the hollow is called the *trough.* The distance between one crest of a wave and the next crest (or between one trough and the next trough) is called the *wavelength.*

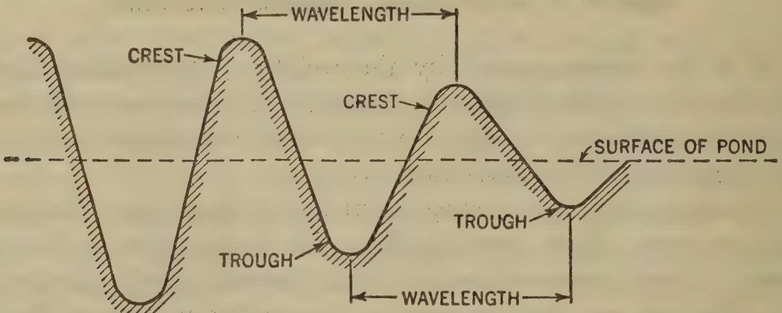

Figure 6. Sectional view of the pond showing what is meant by wavelength.

At the seashore, you may see waves whose wavelengths vary from a few feet up to about a half mile. You may set up a rope wave whose wavelength varies from several inches to several feet.

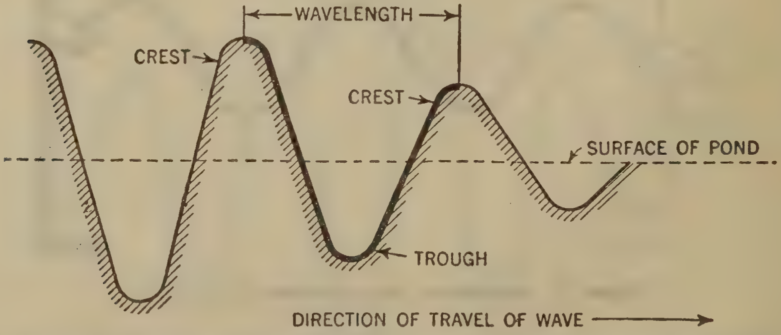

Figure 7. Sectional view of the pond. The heavy line shows the path of the wave going through one cycle.

The *path* that the wave travels in going one wavelength is called a *cycle*. This means the path from one crest through the trough and up to the next crest.

10. Frequency and Amplitude

The number of *cycles* in a given unit of *time* is called the *frequency*. Thus, an ocean wave may have a frequency of about two cycles per minute. This means that the wave will travel through two cycles in one minute.

If you examine the water ripples again, you may notice another interesting thing about them. The larger the pebble you drop, or, the more force with which you throw it, the deeper is the hollow produced and the higher the wall of water set up. The depth of the trough beneath the normal level of the pond or the height of the crest above it is called the *amplitude* of the wave.

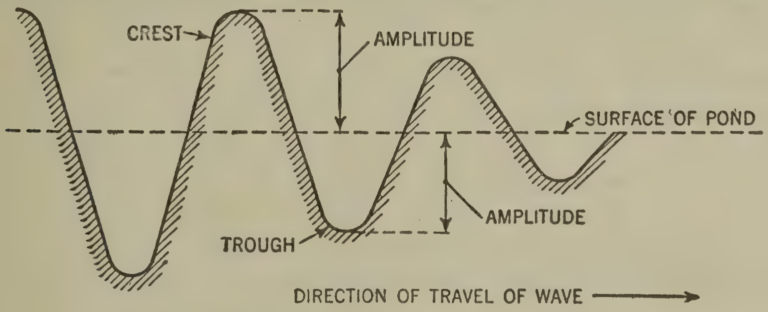

Figure 8. Sectional view of the pond illustrating what is meant by amplitude. Notice that in this kind of wave the amplitude decreases the further the wave travels away from the point of disturbance.

Note that the amplitude of a wave depends upon the force producing it.

Another interesting thing is the *speed* with which a wave passes through a medium. *Since the wave travels from particle to particle in the medium, the type of medium makes a difference in the speed with which a given kind of wave will pass through it.*

SUMMARY

Now let us see what we have learned so far.

A **wave** is energy traveling through a medium by means of vibrations from particle to particle.

The **amplitude** (of a water wave) is the height of the crest of a wave above the surface of the medium at rest.

The **wavelength** is the distance between one crest of a wave and the next crest.

A **cycle** is the path that the wave travels in going one wavelength.

The **frequency** is the number of cycles in a given unit of time.

The **speed** with which the wave travels depends upon the nature of the **medium.**

QUESTIONS AND PROBLEMS

1. Describe what happens when a stone is thrown into a pond.
2. What is meant by a wave?
3. Define what is meant by wavelength. Use a diagram.
4. What is meant by a cycle? What is the relationship between cycles and frequency?
5. Upon what does the amplitude of a wave depend?
6. What determines the speed of a wave?
7. Make a diagram of a series of water waves. Label the following: wavelength, amplitude.
8. How may energy be made to travel from one place to another?

CHAPTER 3

Waves in Ether

Problem: *How do light, heat, and radio waves travel?*

11. Light Waves

See if you can get an electric-light bulb of the type which has a vacuum inside. These bulbs are becoming scarce because it has been found that electric-light bulbs do their work better if filled with a gas like nitrogen. You may still get the vacuum type in a large electrical supply store. Screw the bulb into the electric-light socket and turn the switch. *Light waves,* a type of energy, travel from the hot filament to our eyes. Scientists tell us that light is a wave motion.

Now: since a vacuum surrounds the hot filament, what is the medium which carries the light waves? What is the medium which carries the light waves from the sun to the earth? For scientists say that the space between the earth and sun is empty, or in other words, a vacuum.

12. What is "Ether?"

To get around the difficulty, scientists were forced to assume a medium. They called this medium *ether.* (Note that this ether is not the same as the gas the doctor gives you when he wants to put you to sleep.) Ether, as scientists use the word, is what remains in space when all substance or matter, as we know it, has been taken away. This so-called ether is the medium that transmits the light waves across a vacuum; hence it is called *luminiferous* (that is, light-carrying) *ether.**

---

*The idea of an "ether" was proposed in the latter part of the seventeenth century by Sir Isaac Newton and given prominence by Christian Huygens, the Dutch physicist who discovered polarized light. There is no proof that ether does or does not exist. Some scientists prefer to ignore it. However, since "ether" is a convenient label for the idea of a medium by which all forms of radiant energy (heat, light, radio) are transmitted, it will be used in this text.

Studies have shown that the light wave travels through ether at the enormous *speed* of 186,000 miles (300,000,000 meters) per second. The *frequency* (that is, the number per second) of light waves varies from 375 million millions to 750 million millions of cycles, while their *wavelength* varies from about 15 to 30 millionths of an inch (0.000015 in. to 0.000030 in.).

13. Heat Waves

Now touch the outside of the "burning" electric-light bulb. It is hot. How did *heat,* another type of wave energy, get across the vacuum in the bulb? How do the heat waves sent out by the sun reach the earth?

The heat wave, like the light wave, travels through the ether. Like the light wave, its *speed* is 186,000 miles per second. The *frequency* of heat waves varies from 750,000 millions to 375 million millions of cycles per second and hence their *wavelengths* vary from about one hundredth to 30 millionths of an inch (0.01 in. to 0.000030 in.).

Waves which move in ether as a medium are known as *ether waves.* Light and heat are two forms of energy which travel by ether waves.

14. The Metric System

At this point it should be explained that scientists prefer the *metric system* to the *English system* for the measurement of length. Under the English system you know that

12 inches = 1 foot
3 feet = 1 yard
1760 yards = 1 mile

In the metric system the unit of length is the *meter,* which is slightly more than a yard long (39.37 inches). In this system of measurement the prefix *deka-* means ten, *hecto-* means hundred, *kilo-* means thousand, and *mega-* means million. Similarly *deci-* means a tenth (1/10), *centi-* means a hundredth (1/100), *milli-* means a thousandth (1/1000) and *micro-* means a millionth (1/1,000,000).

Thus a *kilometer* means 1000 meters, and a *millimeter* means

1/1000 meter. The following table may help to make the relationship clear:

10 millimeters (mm) = 1 centimeter (cm)
10 centimeters = 1 decimeter (dm)
10 decimeters = 1 meter (m)
10 meters = 1 dekameter (dkm)
10 dekameters = 1 hectometer (hm)
10 hectometers = 1 kilometer (km)

The relationship between the metric and English systems can be seen from the following table:

1 inch = 2.54 centimeters
39.37 inches = 1 meter
.62 mile = 1 kilometer

The prefixes used in the metric system for length are also used to measure other values. Thus 1000 cycles becomes a *kilocycle* (kc), and 1,000,000 cycles a *megacycle* (mc). Thus, when we say that the frequency of light waves varies from 375 million millions (375,000,000,000,000) to 750 million millions (750,000,000,000,000) of cycles, we may express these numbers as from 375,000,000 megacycles (mc) to 750,000,000 megacycles.

We have taken time out to explain the metric system because you will constantly come across this system of measurement in your scientific studies. As a matter of fact, the frequency of the radio waves from the various broadcasting stations are usually listed in kilocycles (1000 cycles). Thus the frequency of station WOR, New York, is 710 kc (710,000 cycles) per second.

15. Other Forms of Energy

For the light and heat types of ether waves, special organs of our bodies act as *receivers*. However, other forms of energy are transmitted through the ether; we cannot detect these with any of our unaided senses. We must therefore devise special instruments that can change such forms of energy to types which our senses can perceive.

To see the effect of one such type of energy, balance a magnetic needle on a pivot and near it suspend a coil of about 25 turns of No. 18 insulated copper wire. Then pass the current from a dry cell through the coil, and observe that the magnetic needle is sharply deflected. *Energy from the coil of wire passes to the magnetic needle.* To show that it is not the air which transmits the energy, place the whole apparatus under a bell jar and pump out the air. Once again pass the current of electricity through the coil. Again the magnetic needle is deflected. The energy is transmitted across the vacuum.

For want of a better explanation, we again fall back upon the ether and assume that it is the medium which transmits the energy. We say that when an electric current passes through a wire it sets up a *magnetic field* in the ether around that wire.

Note that this magnetic field, unlike the light and heat waves, cannot be received by our senses. Accordingly, we use the magnetic needle to detect this field, and thus to change its energy to a form which our senses can receive. The energy of the magnetic field is changed to the *motion* of the needle; we can see motion.

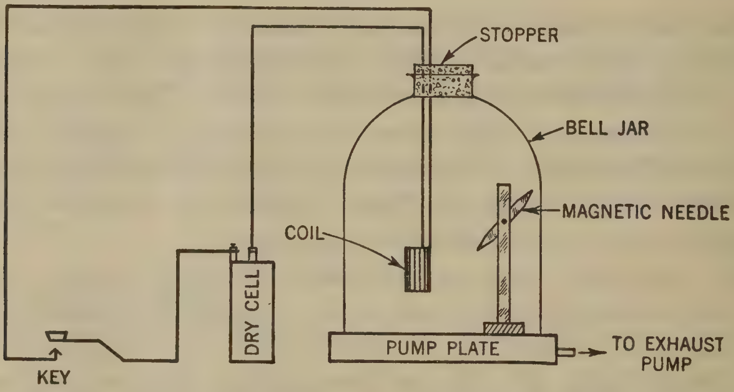

Figure 9. Apparatus to show that electric current, flowing through a coil of wire, will set up a magnetic field around that coil. This field is created even though the coil is surrounded by a vacuum.

All these ether waves are "wireless" waves; they do not depend upon metallic wires to transmit their energy. Because of this fact, these waves may be used to communicate between places where it is not possible to string wires, as between an airplane and the ground. Light waves, as we well know, have been used for communications. To a lesser degree, so have heat waves and magnetic fields.

16. Radio Waves

Light waves travel in straight lines and cannot penetrate opaque objects. Because of this, the curvature of the earth and such intervening objects as houses, trees, hills, and the like, limit the range of this method of communication.

As for heat waves, they are too readily absorbed by surrounding objects to permit them a large range.

The magnetic field is effective for only a very short distance. If, however, the key in Figure 9 is opened and closed very rapidly (ten thousand or more times a second), a type of ether wave new to us, a *radio* wave, is created.

This wave can travel great distances and can penetrate nonmetallic objects. It travels at the speed of light, namely 186,000 miles per second, and its frequency, wave length, and amplitude are determined by the apparatus used to create it.

Radio waves vary in length from about 18 miles down to 1/250 inch. Those used in ordinary broadcasting are from 656 ft. to 1968 ft. (approximately 200 m. to 600 m.) in length.

SUMMARY

The following principles have been discussed in this chapter:

1. Certain forms of radiant energy are transmitted by means of ether waves. These forms are light, heat and radio waves.
2. The idea of a medium called "ether" has been postulated (assumed for practical reasons, although not proven).
3. Radiant energy travels through the ether with a speed of 186,000 miles or 300,000,000 meters per second.
4. The lengths of the waves are determined by the vibration frequency of the source of the waves. The ranges are:

Visible light waves	.00004 to .00008 cm.
Heat waves	.00008 to .04 cm.
Radio waves	.01 cm. to 30 km.

5. The length of an ether wave is found by dividing 300,000,000 meters by the number of vibrations (or cycles) per second.

GLOSSARY

Ether: The medium, permeating all space, which is *supposed* to carry such forms of energy as light, heat and radio waves. There is no proof that ether does or does not exist.

Ether Wave: A wave of energy which uses ether as a medium.

Heat Wave: An ether wave whose wavelength lies between .00008 cm. and .04 cm.

Light Wave: An ether wave whose wavelength lies between .00004 cm. and .00008 cm.

Magnet: A bar of iron or steel or a coil bearing an electric current that has the property of attracting to it pieces of iron, steel or other magnetic substances.

Radio Wave: An ether wave whose wave length lies between .01 cm. and 30 km.

QUESTIONS AND PROBLEMS

1. In what ways are radio, heat and light waves similar? In what ways do they differ?
2. What is the medium for radio waves?
3. At what velocity do light and radio waves travel?
4. Define and give examples of ether waves.
5. For what ether waves are our bodies receivers? For which are our bodies insensitive and in need of special receivers?
6. Why cannot the magnetic field of an electromagnet be used to send wireless messages in a practical manner?
7. Through what materials can radio waves penetrate?

CHAPTER 4

A Simple Radio Receiving Set

Problem 1: *What are the four essential parts of the radio receiver?*

Problem 2: *What is the function of each part?*

It will be helpful in our study of the principles of radio to learn at the start that every radio receiver, no matter how complex or involved, consists of only four essential parts. They are:

1. The *aerial-ground system,* which collects the radio waves.
2. The *tuner,* which selects the radio wave (or station) to be received and rejects all others.
3. The *reproducer,* the device which changes the energy of the radio wave to a form which our senses can perceive.
4. The *detector,* which changes the energy of the radio wave to a form whereby it can operate the reproducer.

This holds true for all receiving sets from the simplest crystal set to the most complex television receiver. Everything else in the receiver is merely a refinement of these four essentials.

WHAT IS THE PURPOSE OF THE AERIAL-GROUND SYSTEM?

17. The Aerial

Suppose we string a copper wire so that one end is up in the air and the other end is connected to the ground. Radio waves, sent out by a broadcasting station, striking this wire, will set up an *electrical pressure* or *voltage* across it. This pressure will cause a small electrical current to flow up and down the wire. We now have the beginning of our radio receiver, the *aerial-ground system.* With it we collect the radio waves. All receivers must have an aerial-ground system. It may be external and connected to the set by wires, or it may be contained in the set itself in the form of a number of loops of wire.

To prove that this aerial-ground system is necessary to the receiver, connect up a regular broadcast receiver with an external aerial and ground. Tune in a station and then disconnect the aerial and ground. The station dies away.*

WHAT IS THE FUNCTION OF A TUNER?

18. Resonance

All radio receivers must have some method of separating the station desired from all other stations broadcasting at the same time. The apparatus which does this is called the *tuner.* Since each station sends out radio waves of a different frequency, the tuner must select the frequency desired and reject all others.

To understand how this is done you must first learn about *resonance.*

Place a number of drinking glasses of different size, shape, and thickness upon a table. Strike each with a pencil. Observe that each glass gives off a different tone. The vibrating glasses set up air waves which reach our ears and are interpreted as sound. The different tones are caused by the different frequencies of these air waves. This means that the glasses, too, are vibrating at different frequencies. The frequency at which an object will vibrate when struck depends upon its material, size, shape, and thickness. This frequency is called the *natural frequency* of the object.

19. Vibrations of a Pendulum

From a nail, suspend a small weight at the end of a string about a yard long. You now have a pendulum. Start the pendulum swinging gently. You will note that it swings a certain number of times per minute. That number is the natural frequency of that particular pendulum. Wait till it is swinging gently. Now, every time the pendulum reaches the end of its swing, give it a very light tap. You will soon have your pendulum swinging violently to and fro. Note that you must tap the pendulum at the exact instant it reaches the peak of its swing if you wish to increase that swing. If you tap it too soon or too late, the pendulum will slow down. The increased energy of the swing came from the tapping. Therefore, to obtain the maximum transfer of energy from the tapping to the pendulum, the *frequency of the tapping must be equal to the natural frequency of the pendulum.* We say the tapping is in *resonance* with the swing of the pendulum.

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* The station may be faintly received even after the aerial and ground are disconnected. This is because the wires in the set itself act as a very inefficient sort of aerial and ground.

20. Tuning Blocks

Here is another experiment you may perform. Obtain two tuning blocks of similar frequency, say, 256 vibrations per second, which corresponds to the note we call middle C on the piano. A tuning block is a bar of steel so designed that it will vibrate at a certain frequency when struck. This bar is mounted on a hollow wooden block which amplifies the note produced.

Place these blocks about 10 feet apart. Now strike one of them vigorously. It will give off its note, middle C. Place your hand on the block you struck to stop its vibrations. You will continue to hear the note, although a good deal fainter. Bring your ear near the second block. The sound will be coming from it, although you did not strike it. Place your hand on the second block. The sound stops.

Let us see what happened. When you struck the first block it was set vibrating at its natural frequency of 256 vibrations per second. The vibrating bar set up air waves at that same frequency. These air waves struck the second block. Since the frequency of the air waves was the same as the natural frequency of this second block, the energy of the air waves was transferred to the block and it was set in vibratory motion. The second block thereupon set up air waves of its own, and it was these waves you heard when you stopped the vibrations of the first block. We say that the two blocks are in *resonance* with each other.

Repeat this experiment using two tuning blocks of different frequency, say, one at 256 or middle C and the other at 288 or D. This time you get no sound from the second block because the air waves are not vibrating at the natural frequency of the second block and therefore there is no transfer of energy. These blocks are *not in resonance* with each other.

So you see that you have here a means of selecting only a certain frequency and rejecting all others. All you have to do is to construct your receiving block so that it is in *resonance* with the frequency you wish to receive. It will vibrate only when air waves of that frequency hit it but not at any other frequency.

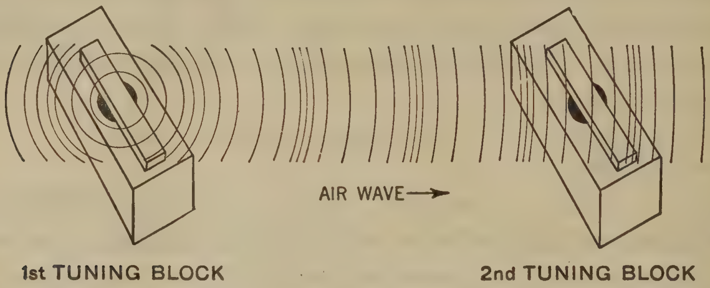


Figure 10. Set of two tuning blocks showing how air waves sent out by the first block strike the second one and set it vibrating.

21. Radio Tuning Means Putting a Receiver in Resonance with Certain Radio Waves

In our radio receiver we use the same principle that was shown by the tuning blocks. Assume that three stations A, B, and C are broadcasting simultaneously at frequencies of *a, b,* and *c* respectively. If you wish to receive station A, you adjust your tuner so that the natural frequency of your receiver is the same as the frequency *a* of the radio wave from station A. The receiver now is in resonance with the radio wave from station A, and the energy of the radio wave is transferred to the receiver. Since stations B and C are not in resonance with the receiver, the energy of the radio waves sent out by these stations is rejected and we do not hear them.

WHAT IS THE FUNCTION OF THE REPRODUCER?

22. How Do We Hear the Signals?

So far, we have been able to catch or collect the radio waves by means of the aerial-ground system and to select the station (or frequency) we desire by means of the tuner. But we still cannot hear or see the electric currents which have been set up in our receiver. What we now need is some device which will change this electric current to a form of energy which we can hear or see. This device is called the *reproducer.*

Using copper wire, hook up a telephone transmitter, a telephone receiver, and some dry cells as shown in Figure 11.

23. The Telephone as a Reproducer

The electric current flows from the dry cells through the copper wire, through the telephone transmitter, then from the transmitter through the copper wire, through the telephone receiver, and then through the copper wire back again to the dry cells. We call this hookup an electrical circuit.

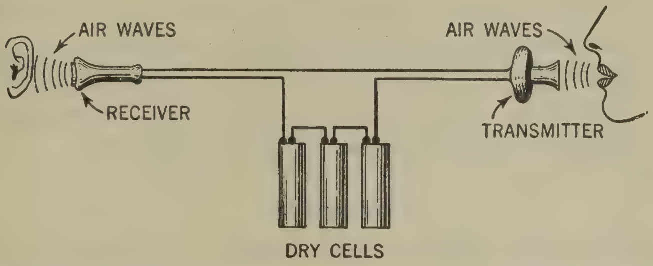


Figure 11. Hookup of a telephone transmitter, telephone receiver, and dry cells, showing how air waves, striking the transmitter, are heard as sound coming from the receiver.

When you speak into the telephone transmitter, the sound waves hitting it cause it to act like a gate, allowing more or less electric current to flow through the circuit. A fluctuating electric current is thus set flowing in the circuit. At the other end of the line, in the telephone receiver, this fluctuating electric current causes a metallic diaphragm to fluctuate in step with the current. This movement of the diaphragm causes the air next to the diaphragm to move back and forth, setting up air waves; we hear these air waves as sound. Since the air waves that hit the transmitter move the same way as the air waves set up by the diaphragm of the receiver, you hear the same sound as was spoken into the transmitter. We call the telephone receiver a *reproducer.*

Now, remember that radio waves set up an electric current in an aerial-ground system, as we discovered earlier. Hence it would seem that all you have to do to hear a radio message from a distant station is to lead this electric current through the tuner and into some type of telephone receiver.

But not so fast. There are some electric currents that cannot operate the telephone receiver. The current that the radio wave sets up in your aerial-ground system is of this type. So it is necessary to change it to current of a type that will operate the reproducer.

WHAT IS THE FUNCTION OF THE DETECTOR?

24. The Detector

There are a number of ways of accomplishing the change of current from one type to another. The simplest, perhaps, is to compel the current to pass through a certain type of mineral such as *galena.* This passage changes the aerial-ground current into a current type that will operate the telephone receiver and make it possible to hear the radio wave as sound. Such a device, which changes the electric current set up by the radio wave into a form that will operate the reproducer, is called a *detector.*

SUMMARY

Here, then, is your complete radio receiver. First of all is the **aerial-ground system,** which collects the radio waves. Next comes the **tuner,** which selects the station or radio wave desired and rejects all the rest. Then comes the **detector,** which changes the form of the electric current set up by the radio wave into a form that will operate the **reproducer,** which in turn produces the sound that we can hear.

GLOSSARY

Aerial-Ground System: The wire system which "picks up" radio waves and across which the radio wave produces an electrical pressure.

Detector: The device to change the electrical currents which are produced in a receiver by radio waves into electrical currents which can operate the reproducer.

Natural Frequency: The frequency at which a body will vibrate if kept free from outside interference.

Reproducer: A device such as a telephone receiver which changes electric currents to a form which our senses may observe.

Resonance: The condition of two vibrating bodies when the natural frequency of one body is equal to the frequency of the other vibrating body. In the radio receiver, when the natural frequency of the tuner is the same as the frequency of the transmitting station, the two are in resonance.

Tuner: The device in a radio receiver which selects a radio wave of a certain frequency and rejects all others.

QUESTIONS AND PROBLEMS

1. What are the four essentials of all radio receivers?

2. What effect is produced when a radio wave sweeps across an aerial-ground system?

3. Explain the function of a tuner in a radio receiver.

4. In what manner does resonance of the tuner relate the receiver to the radio wave of a station?

5. Upon what factors does the natural frequency of the tone of a drinking tumbler depend?

6. Why must a reproducer be used in a radio receiver?

7. Why must a receiver have a detector?

8. What material may be used in an aerial-ground system to pick up radio waves?

CHAPTER 5

The Aerial-ground System

Problem 1: *How is a simple antenna set up?*
Problem 2: *How is the aerial connected to the ground?*

Before we continue our study, let us have clearly in mind what we are trying to do. The plan of this book proposes to take up the problems of radio in the following order:

1. What are the parts of a radio receiving set?
2. How are these parts connected and how do they work?
3. Why do the parts function as they do?

We have learned that the radio wave, striking the aerial, sets up an electric pressure, called an electromotive force (abbreviated E.M.F.) which causes a small electric current to flow up and down the aerial-ground system. Because this current is extremely small it is necessary to construct your aerial-ground system as efficiently as possible and you must be sure that you do not waste this current once it is set flowing.

25. The Antenna

First of all there is the aerial or antenna. For ordinary broadcast reception, the simplest type of aerial consists of a single strand of wire about 75 ft. long. This wire should be of copper, of No. 12 or No. 14 gauge and may either be insulated or bare. It should be raised as high above ground as is practical and should be kept clear of all obstructions, metal especially. *Insulators* should be attached to both ends to prevent the small currents from leaking off. Insulators are substances that do not conduct electricity. Common examples are glass, porcelain, bakelite, and hard rubber. If a power line or a trolley wire runs nearby, your aerial should run at right angles to that line or wire.

26. The Lead-in

After the *aerial* comes the *lead-in.* This is a piece of wire similar to the aerial. It is connected at one end to the antenna and at the other end to the receiving set. If possible, the aerial and lead-in should be made of one piece of wire. But if you should have to join one piece of lead-in wire to another, or to the aerial, be sure to scrape the two pieces clean with a knife or sandpaper. Then twist one wire securely around the other. For best results this joint should be soldered. Finally, wrap friction tape around the joint to prevent the air from corroding it.

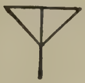
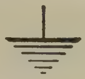
The lead-in should be kept at least 6 in. away from all walls and other surrounding objects. It is usually brought in through a window, and, to avoid the necessity of drilling a hole in the frame, the lead-in is cut and a flexible window strip is inserted. This window strip lies flat under the window frame and permits the window to be opened and closed without disturbing the installation.

From the inside end of the window strip, connect an insulated copper wire to the post on your radio set marked ANT or AERIAL. For best results, the lead-in should be about 25 ft. in length, from the aerial to your radio set.

27. The Ground

Finally, there is the *ground* connection.* The best connection for a ground, if one is available, is a cold-water pipe. Next best is a radiator or any other pipe which goes to the ground. Gas pipes should *never* be used as grounds. Scrape the paint off the pipe where you plan to make the connection. Then wrap a number of turns of bare copper wire tightly around the cleaned part of the pipe.

Better yet, get a ground clamp designed for this purpose and attach it on to the pipe at the point selected. Then run a piece of insulated copper wire from your ground connection to the post marked GROUND or GND on your radio set. This wire should be about No. 18 gauge and should be as short as possible.

When we draw a diagram of our radio set we use symbols to signify the various parts. The symbol used for the aerial and lead-in is  and that used to signify a ground is: 

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* Ground is a technical term used in radio work. It refers to a part of a circuit which is directly connected either to the earth or to the metallic base of some device. In an automobile one terminal of the battery is connected to the steel frame of the car; this is a *ground.* Hence in the automobile there is only one wire leading to a lamp or other fixture, the circuit being completed by connecting it through the frame.

It should be understood that the aerial-ground system just described is a very simple type. In a later chapter some other types will be discussed, types better adapted to certain purposes.

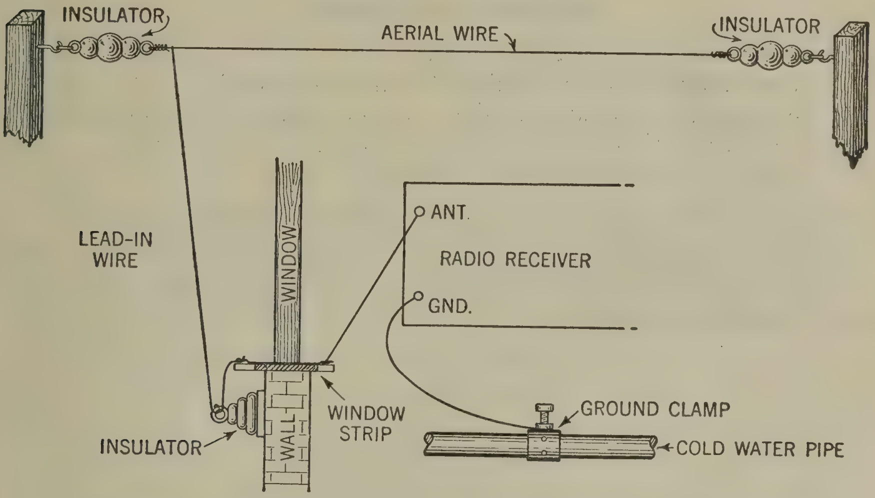


Figure 12. Diagram illustrating the installation of the aerial-ground system.

SUMMARY

1. The **aerial-ground system** consists of three parts: the **antenna or aerial,** the **lead-in** wires, and the **ground.**

2. The function of this system is to receive and capture some of the radio waves being sent out by broadcasting stations.

GLOSSARY

Aerial or Antenna: An elevated conductor, usually of copper, insulated from its supports and the ground and connected to the receiving set by the lead-in wire.

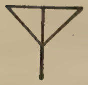
Conductor: Any substances, usually a metal wire, through which a current of electricity can flow freely.

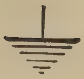
Ground: A water pipe, or some such arrangement, by which the receiving set makes contact with the earth. See also footnote, p. 28.

Insulator: Any substance through which a current of electricity cannot flow freely.

Lead-in: An insulated wire connecting the aerial to the receiving set.

SYMBOLS


Aerial and lead-in.


Ground.

QUESTIONS AND PROBLEMS

1. Describe a simple type of aerial.
2. What is meant by an insulator? Give examples.
3. How must aerials near trolleys or power wires be set up?
4. What precautions must be taken in setting up a lead-in?
5. What is the best length for a lead-in?
6. What objects may best be used to connect our ground wires?
7. Draw the symbols for an aerial and lead-in; for a ground.
8. How should the ground connection be installed?
9. Describe the complete installation of an aerial, giving size, materials, and other details.

CHAPTER 6

The Tuner

Problem 1: *What are the principles of a tuning system?*
Problem 2: *What do we mean by inductance and capacitance?*

You have already learned that the tuner selects the desired radio station by adjusting the natural frequency of the receiver so that it is in *resonance* with the transmitter frequency. Let us see what determines the natural frequency of the receiver.

Examination of the tuner shows that it consists of two parts—a coil of wire to provide *inductance* and a condenser to serve as a *capacitance.* It is the electrical size or value of this combination of coil and condenser that determines the natural frequency of the receiver, even as the size and weight of a tuning block determine its natural frequency. Both inductance and capacitance (or capacity) have technical meanings, which will be explained in later chapters. For the present let us consider inductance to be the electrical disturbance in the coil caused by the influence of (or induced by) the radio waves. By capacitance, we refer to the ability (or capacity) of a condenser to hold or store electric charges.

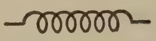
28. The Inductance

The device that takes care of the *inductance* consists of a coil of wire wound around a tube usually made of cardboard or bakelite. Its electrical value depends on:

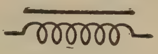
1. The number of turns or loops of wire.
2. The length of the coil of wire.
3. The diameter of the tube on which it is wound.
4. The core of the coil. This is the material inside the tube. The two most common materials for

the core are air and iron. Air-core coils are usually used for the tuner.

The unit for measurement of inductance is the *henry* (h.) or the *millihenry* (mh.). (See Chap. 32, Vol. II.) The millihenry is one one-thousandth of a henry. The symbol for inductance devices or *inductors* having cores of air or iron are:

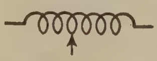


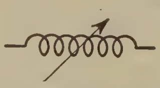
AIR CORE

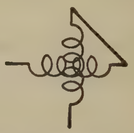


IRON CORE

We can vary the value of our inductance by changing one or more of the four factors listed above. It is most convenient to change the number of turns or loops of the coil. The symbol for a variable inductor is any of the following:







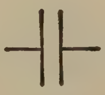
Whenever we desire to represent inductance in an electrical formula or equation we use the letter L.

29. The Capacity or Capacitance

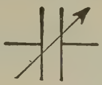
The *capacitance* in a tuner is provided by a device called a *condenser*. This condenser is made of two or more metal plates facing each other and separated by some substance which will not conduct electricity. This substance is called a *dielectric* and usually consists of air, paper, mica, oil, or glass. The plates are usually made of brass, tinfoil, or aluminum. The electrical value of a condenser depends on:

1. The total area of the plates facing each other.
2. The material of the dielectric.
3. The thickness of the dielectric (or distance between plates).

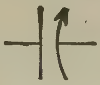
The unit of measure of capacitance is the *farad* (f.). For radio purposes we usually use the microfarad (μfd.) which is one-millionth of a farad and the *micromicrofarad* ($\mu\mu$fd.), which is one one-millionth of a microfarad. (Chap. 33, Vol. II.) The symbol for the condenser is:



We can vary the value of our condenser by changing one or more of the three factors listed above. The most convenient method is that of changing the area of the plates facing each other. This is done by making one plate, or set of plates, rotary, and the other plate, or set of plates, stationary. All the stationary plates are joined together, giving the effect of one large stationary plate. The same is done with the rotary plates. The rotary plates move in and out between the stationary plates. Thus, the more the rotary plates are moved in between the stationary plates, the greater the area of the plates facing each other and the greater the capacitance of the condenser. The symbol for a variable condenser is:



or



Whenever we desire to represent capacitance in an electrical formula or equation we use the letter *C*.

30. The Tuning Circuit

If, by means of wire, you connect a coil and condenser as shown in Figure 13, you create a tuning circuit. When you apply a voltage (electrical pressure) across this circuit, you will cause an electrical current to vibrate back and forth through it. We speak of such electrical vibrations as *oscillations*. These oscillations are more fully discussed in Chapter 12.

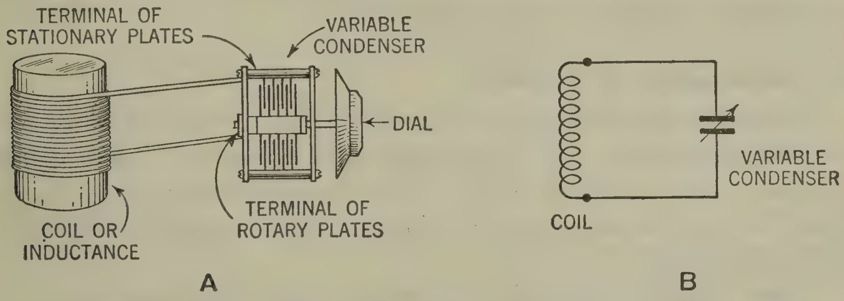


Figure 13. Hookup showing how coil and variable condenser are connected to form the tuning circuit. Figures A and B are identical, A being the pictorial method of showing the circuit while B is the schematic method using symbols.

The natural frequency of the oscillations in this circuit is determined by the product of the values L and C ($L \times C$ or LC).

The transmitting station uses a condenser and coil hookup similar to the one we have just described to generate the radio wave it sends out. The frequency of its wave is determined by the $L \times C$ of the transmitting set. Should the $L \times C$ of the transmitting station equal the $L \times C$ of your receiver, your set will be in resonance with the transmitter. You will then receive that station only and no other.

Note that it is not necessary to have the same L and C in your receiving set as is in the transmitting station. It is enough that the product of L and C ($L \times C$) of your set be equal to the $L \times C$ of the transmitter. So if we arbitrarily give a value of 4 to the L and 4 to the C of the transmitting station, the $L \times C$ of that station is 16. To bring your receiver in resonance with the transmitter (that is, to *tune* your set for reception) you may choose an L whose value is 2 and a C whose value is 8. Or else you may choose an L of 8 and a C of 2. Or an L of 4 and a C of 4. In other words, you may choose any value of L and C whose product is equal to 16, the same as the $L \times C$ value of the transmitter.

Now all this is very well if you wish to build a receiver which will receive only one station. But if you wish to receive another station you must be able to vary the L or C (or both), of your receiver so that the new $L \times C$ will be equal to the $L \times C$ of the new station.

It has been found that it is most practical to vary the C, using a variable condenser for that purpose.

31. Construction of a Tuner

Now you are ready to build your tuner. Obtain a cardboard mailing tube about 2 in. in diameter and about 6 in. long. Upon this tube wind 90 turns of No. 28 gauge insulated copper wire so that the turns lie next to each other and form a single layer. This is your inductor.

Now obtain a variable condenser whose maximum value is .00035 microfarads (μfd.). Such a condenser usually has from 17 to 21 plates, half rotary and half stationary. Connect one end of the coil to the rotary-plate terminal of the condenser and the other end of the coil to the stationary-plate terminal, as shown in Figure 13. You now have constructed your tuner.

SUMMARY

1. The **tuning system** consists of two essential parts: a **coil** of wire and a **condenser**.

2. The coil provides a means of receiving the electrical impulses

imparted to the antenna by the radio waves. It accomplishes this by **inductance.**

3. The condenser serves as a storage place for electric charges and its ability to store them is called **capacitance** or **capacity.**

4. The mutual action of the inductance and capacitance results in the setting up of **oscillations** in the tuning circuit.

5. These oscillations may be put in **resonance** with those of a broadcasting station by making the values of L (inductance) and C (capacitance) such that the product $L \times C$ is identical with the product $L \times C$ of the desired station.

6. **Tuning** is achieved by using a variable condenser by which capacitance (C) can be given any desired value.

GLOSSARY

Condenser: Two sets of metal plates separated by an insulator or dielectric.

Condenser, fixed: A condenser whose plates are fixed so that its electrical value cannot be changed.

Condenser, variable: A condenser whose plates can be moved so that its electrical value can be changed at will.

Dielectric: An insulator placed between the plates of a condenser.

Farad: The unit used to measure the electrical value of a condenser.

Henry: The unit used to measure the electrical value of an inductor.

Inductor: A coil of wire wound on a form.

L × C: The product of the electrical values of the inductor and condenser of the tuning circuit which determines its natural frequency.

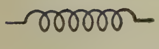
Micro- (prefix): $\frac{1}{1{,}000{,}000}$.

Micromicro- (prefix): $\frac{1}{1{,}000{,}000{,}000{,}000}$.

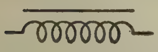
Milli- (prefix): $\frac{1}{1{,}000}$.

Oscillation: The to and fro surge of an electric current in a circuit.

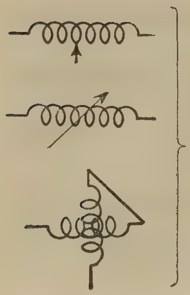
SYMBOLS



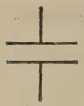
Coil wound on nonmetallic core.



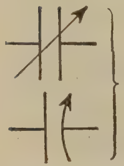
Coil wound on iron core.



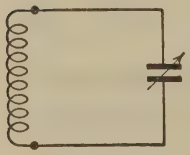
Variable coil.



Fixed condenser.



Variable condenser.



Tuner circuit.

QUESTIONS AND PROBLEMS

1. What determines the natural frequency of the tuner of a receiver?
2. Upon what factors does the electrical value of an inductance coil depend?
3. Give the unit of inductance.
4. What is the most convenient method of varying the inductance of a coil?
5. Describe the essential parts of all condensers.
6. List several dielectric materials.
7. Upon what factors does the electrical value of a condenser depend?
8. Give the meaning of milli-, micro-, and micromicro-.
9. What is the most convenient method of varying the capacitance of a condenser of a tuner?
10. Draw a tuner circuit showing the connections of the parts.
11. What determines the natural frequency of oscillations of a tuner circuit?
12. When will a receiver be in resonance with a particular transmitter?
13. Must the physical size of a tuner at a broadcasting station be the same as that of our receiver picking up that station? Give an explanation.
14. How is the natural frequency of a tuner circuit varied in common practice?

CHAPTER 7

The Reproducer

Problem 1: *What are the principles of the reproducer?*
Problem 2: *How does a telephone receiver work?*
Problem 3: *What are the principles of a loudspeaker?*

32. Magnetism

To understand how the reproducer works, you must learn a few facts about magnetism and electromagnetism. Cut a circular disk of thin iron about 2 in. in diameter. Obtain a bar magnet and hold it near your iron disk. The magnet is surrounded by an invisible magnetic field of force which acts on the disk, and pulls it towards the magnet.

Obtain a piece of soft iron rod or bar stock about 1 in. in diameter and 2 in. long. Be sure it is not magnetized. Now wind upon it a coil of about 25 turns of No. 18 gauge insulated copper wire. Connect the ends of the coil to the posts of a dry cell. When the current flows through the coil the bar becomes a magnet. It has a magnetic field which will attract the iron disk just as did the bar magnet. When the current ceases to flow through it, the coil loses its magnetism. We call such a combination of a bar in a coil that is carrying current an electromagnet.

33. Effect of a Varying Current

Mount the bar magnet upright on a board. Remove the soft iron bar from the coil and slip the coil over the bar magnet. Above the magnet, and separated from it by about an inch, suspend your disk from a spring balance. This balance will show how much pull is being exerted on the disk.

Measure the pull which the bar magnet exerts on the disk. Connect the coil to the posts of a dry cell. The pull should increase because you now have the double pull of the bar magnet and the electromagnet. (Should the pull decrease, reverse the connections to the dry cell.)

Now connect another dry cell *in series* with the coil. To connect this properly, disconnect the end of the coil from the outer post of the first dry cell. Connect this outer post to the center post of the second dry cell and connect the wire from the coil to the outer post of the second dry cell. Cells connected in this manner are *in series*.

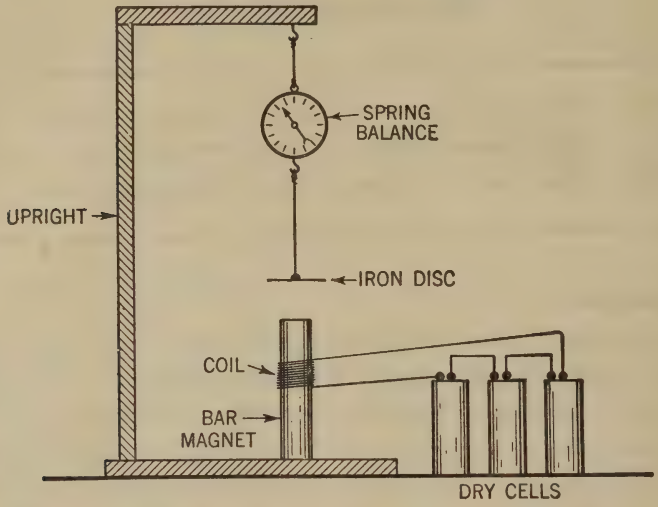


Figure 14. Apparatus used to show that a varying electric current passing through an electromagnet will exert a varying pull on an iron disk.

You will observe that the pull is greater. This is to be expected because using two dry cells in series increases the current and makes the electromagnet stronger. Repeat, using three or more dry cells. As you add cells the pull becomes greater, because more current is flowing through the coil of the electromagnet. Reducing the number of dry cells reduces the current in the electromagnet coil and the pull on the disk becomes weaker. If you pass a fluctuating current through the coil the pull on the disk will fluctuate in step with the current. Note that a steady current will not cause the disk to move. It will be pulled to a certain position and then will remain stationary as long as the current is steady.

34. Construction of a Telephone Receiver

Now get a telephone receiver and unscrew the cap. You will see a thin iron disk; this disk is called the diaphragm. Remove the diaphragm and you will see a coil of wire (the electromagnet coil) which is wound over the end of a bar magnet. The ends of the wires connecting the electromagnet pass out through the far end of the telephone receiver.

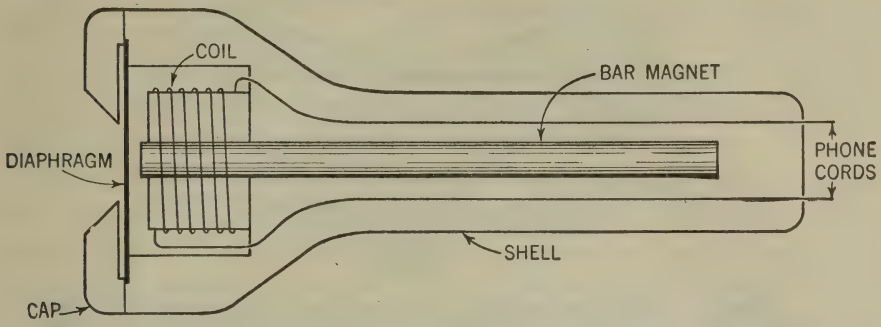


Figure 15. Construction of a telephone receiver.

The bar magnet exerts a constant pull on the diaphragm. Since the diaphragm is held fast at its rim, it can only move inward toward the magnet at its center. The springiness of the diaphragm constantly tends to pull it back. When we add the pull of the electromagnet the diaphragm bends inward much or little, depending upon the current flowing through the coil. You see then that a fluctuating current flowing through the coil causes the diaphragm to fluctuate in step with it.

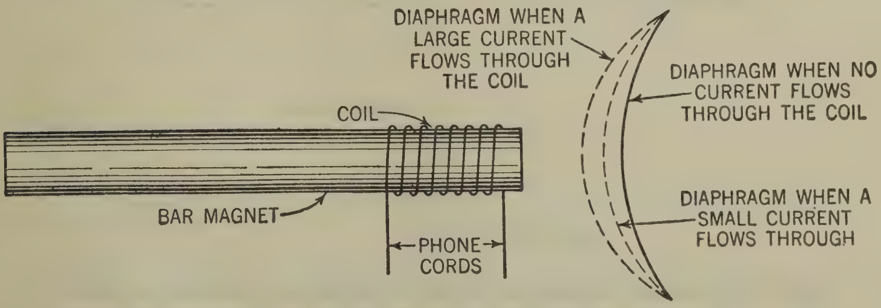

DIAPHRAGM WHEN A LARGE CURRENT FLOWS THROUGH THE COIL
DIAPHRAGM WHEN NO CURRENT FLOWS THROUGH THE COIL
COIL
BAR MAGNET
PHONE CORDS
DIAPHRAGM WHEN A SMALL CURRENT FLOWS THROUGH

Figure 16. Diagram showing positions of diaphragm as a fluctuating current flows through the electromagnet of the phones. The bending of the diaphragm is greatly exaggerated in this drawing.

Now look back to Figure 11. You will remember that the sound waves striking the telephone transmitter cause a fluctuating current to flow through the circuit. This current fluctuates in step with the sound waves. This current is sent through the electromagnet coil of the telephone receiver and the diaphragm is thus made to fluctuate in step with the original sound waves. The moving diaphragm sets the air next to it in motion, and it is these air waves which hit our ear. Thus we hear a sound which is the same as that which was spoken into the telephone transmitter.

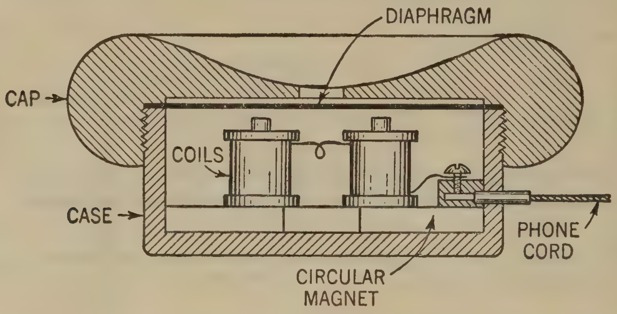


Figure 17. Diagram showing a sectional view of an earphone of the type used in radio receivers. Note how flat it is as compared to the telephone receiver. The permanent magnet here is made either circular or horseshoe shaped.

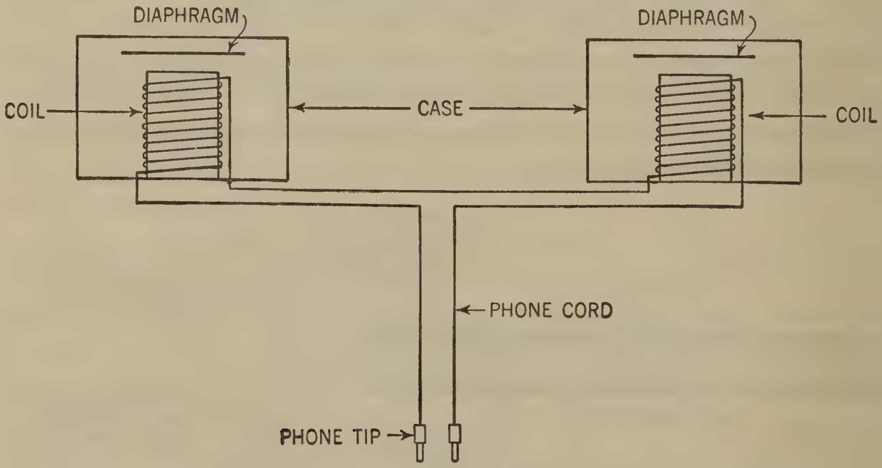
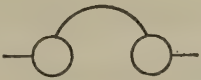


Figure 18. Diagram showing how a pair of phones are connected in series.

For the sake of convenience, the earphones used for radio reception (called simply *phones*) are made flat. This flattening is accomplished by using a circular magnet instead of the long, straight one used in the telephone receiver.

Usually two of these phones are connected together in series, one for each ear, and held in place with a metal band or spring that fits over the head.

The symbol for earphones is: 

35. The Magnetic Loudspeaker

You have seen that the moving diaphragms of the earphones set the air next to them in motion and thus produce the sound you hear. If this sound were loud enough, you could lay the phones on the table and would not need to bother wearing them on your head.

If you were to make one of the diaphragms larger it would move a greater quantity of air and thus produce a louder sound. For practical reasons a diaphragm cannot be made very large, and so another scheme was developed. One end of a stiff wire is fastened to the center of the diaphragm. This wire now moves in and out in step with the diaphragm. To the other end of the wire a large paper cone is fastened. The fluctuating diaphragm moves the wire; the wire in turn moves the paper cone. This in turn sets a large amount of air in motion, creating a loud sound. By this means we are able to do away with earphones. The device is called the magnetic loudspeaker.

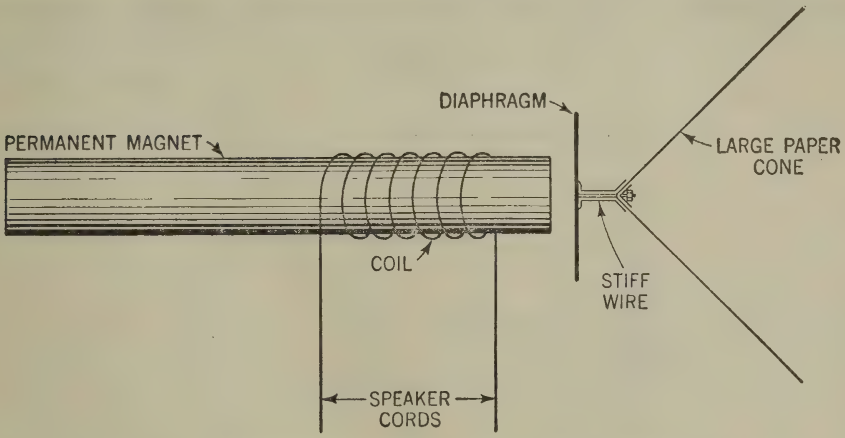


Figure 19. Diagram showing how an earphone is converted to a loudspeaker.

SUMMARY

1. A coil of wire surrounding a core of soft iron becomes an **electromagnet** when an electric current passes through the coil.

2. The strength of the **magnetic field** (that is, its attractive force)

increases when the current increases and decreases when the current decreases.

3. The **telephone receiver** is an application of the electromagnet. Variations in the electric current caused by the sounds in the transmitter are reproduced in the receiver and cause fluctuating magnetic strength. A metal **diaphragm** is pulled in and out as the current is stronger or weaker. This diaphragm produces sound waves in the air.

4. **Earphones** are telephone receivers with flat electromagnets.

5. **Loudspeakers** are comparable to telephone receivers in which the diaphragm is attached to a large cone. The cone sets in motion a larger amount of air and hence gives a louder sound.

GLOSSARY

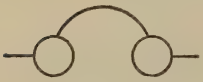
Diaphragm: A thin iron disk which is set vibrating by the flow of the electric current through the coil of the earphone. This disk causes the air to vibrate, thus creating sound waves.

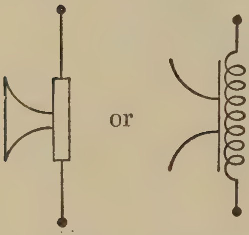
Earphones or **phones**: Two flat receivers, held on the head by a spring.

Electromagnet: A magnet made by electric current flowing through a coil of wire surrounding a core.

Loudspeaker: A reproducer which produces a loud, audible sound.

SYMBOLS


Earphones or phones.



Loudspeaker.

QUESTIONS AND PROBLEMS

1. How would you construct an electromagnet?

2. How may you increase the strength of an electromagnet?

3. Under what conditions will current passing through a set of earphones fail to produce sound?

4. Describe the action of the diaphragm of an earphone under the following series of events: no current followed by an increasing current, followed by a decreasing current in the earphone.

5. In what manner are the phones of a set of earphones connected?

CHAPTER 8

The Detector

Problem 1: *What is the electron theory?*
Problem 2: *How is an alternating current changed to a pulsating direct current?*
Problem 3: *How can we make a practical detector?*

In studying the aerial and tuner you have learned that the radio wave, striking the aerial, sets up a voltage or electrical pressure in it which, in turn, causes a small current to flow in the receiver. But if you connect your phones to this circuit, you will hear nothing.

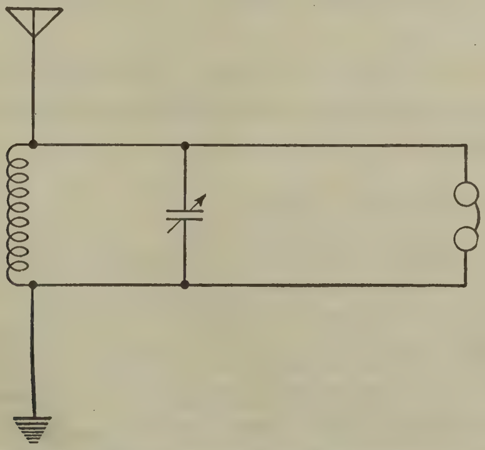


Figure 20. Diagram showing the aerial-ground system and the tuner connected to a set of phones. This circuit will not work.

36. What Is Electricity?

To understand why the electrical current flowing in the receiver fails to operate the phones, we must first consider the theory of electricity. Although scientists have succeeded in putting electricity to a great many uses, they do not know just what electricity is. It is one of the many forms of energy and may be changed into other forms such as heat, light, and motion. From a study of the behavior of an electric current and from a study of the methods of producing electric phenomena, scientists have arrived at some theories about its nature.

37. Hypotheses, Theories and Laws

When a scientist tries to explain one of nature's mysteries, he carefully examines all the facts he can obtain. He makes experiments to obtain more facts and then makes a guess that tries to explain all the facts. This guess is at first called a *hypothesis*. When more evidence is found to support it, and other scientists generally accept it, the explanation is called a *theory*. After a time, someone may come along with proof which shows the theory to be true. We then call the explanation a *law*. Or someone else may come along with facts to show that the theory cannot be true. In the latter case the theory may be modified to take the new facts into account or discarded entirely in favor of a new theory which tends to explain the new facts. Some scientific theories existed a great many years before they were proven to be true or false.

So it is with the electric current. Although we do not know what it is, we have a theory which tries to explain it. It is called the *electron theory*.

38. What Is the Electron Theory?

According to the electron theory (Chap. 29, Vol. II.) an electric current consists of the movement of minute particles, negatively charged. These particles are called *electrons*. While some of these electrons will drift through a conductor like water flowing through a pipe, the main movement of these electrons consists in hitting their neighbors and by that means passing along the impulse of energy which we call an electric current. The action is somewhat similar to that of the dominoes of Figure 4.

This impulse of energy travels at the rate of nearly 186,000 miles per second, or nearly the same speed as light. When the electric current flows in one direction through the conductor, we say it is *direct current* (D.C.). If the current flows first in one direction and then reverses itself and flows back in the opposite direction, we say it is *alternating current* (A.C.). When an alternating current flows in one direction, stops, and then flows in the opposite direction we say the current has gone through one *cycle.* The number of cycles per second is called the *frequency.*

39. Alternating Currents

The electricity used to light your house may be alternating current and have a frequency of 60 cycles per second. The current set flowing in your aerial-ground system by the action of the radio wave also is alternating current; its frequency is the same as the frequency of the radio wave. That is, it may vary from 10 kilocycles (kc.) per second to 3,000,000 megacycles (mc.) per second. Electric current whose frequency falls within that range is said to be *radio-frequency alternating current.*

Now let us go back to our radio receiver. Let us assume that a broadcasting station sends out a radio wave whose frequency is 500 kc. per second. This frequency we call *radio frequency* (R.F.). The radio wave hits our aerial and sets a current flowing in our aerial-ground system. This is an alternating current whose frequency is the same as that of the radio wave, namely, 500 kc. per second. This in turn starts an alternating current of the same frequency flowing in the tuner. It is this current which you have applied to the phones in Figure 20.

Let us see what happens in the phones. For one one-millionth of a second the current flows in one direction through the electromagnet of the phones. This causes the pull of the electromagnet to be added to that of the bar or permanent magnet. The diaphragm is therefore pulled a little closer to the magnet.

For the next one one-millionth of a second the current reverses itself and is now flowing through the electromagnet coil in the opposite direction. Now the magnetism of the electromagnet is subtracted from that of the permanent magnet and the total magnetic pull is less than before. The diaphragm starts to spring back. This process occurs every time the current reverses itself, which is once every millionth of a second.

Now one one-millionth of a second is a very small interval of time and there is no diaphragm that is so sensitive that it can follow these changes. Every time the diaphragm begins to be pulled towards the magnet, the current reverses itself and the pull is released. As a result the diaphragm stands still and you hear no sound.

40. Pulsating Currents

To overcome this difficulty, someone had a brilliant idea. Suppose we put a gate in the circuit which permits an electric current to flow only in one direction and not in the other. Now let us see what happens to the radio-frequency alternating current in the circuit. For one one-millionth of a second the current will flow through the gate. During the next one one-millionth of a second the gate will block the current and there will be no flow. Then a flow in the same direction as the first. Then no flow. And so on. The effect of the gate will be to permit a series of pulses of current to flow, all going in the same direction. These pulses of current will be separated by intervals when there is no flow. Each pulse and interval will last only one one-millionth of a second.

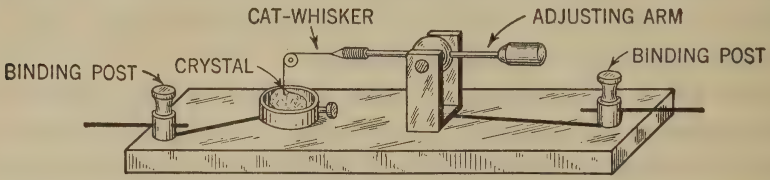


Figure 21. Diagram showing the construction of a crystal detector.

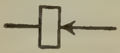
Since the current now flows only in one direction we call it direct current. Since it is not a steady flow, but consists of a series of pulses, we call it *pulsating direct current.*

Let us see what happens when the pulsating direct current flows into our phones. For one one-millionth of a second the pull of the electromagnet is added to that of the permanent magnet and the diaphragm starts to bend in. For the next millionth of a second the electromagnet will exert no pull and the diaphragm will start to spring back. Before it can move back, however, the next pulse enters the electromagnet coil and the diaphragm is pulled a little closer. This continues and as a result of these streams of pulses the diaphragm is set vibrating and we can hear a sound.

41. A Detector Is an Electrical Gate

The device used in radio which serves as a one-way gate is called a *detector.* Scientists have discovered that certain crystals like *carborundum* and the mineral *galena* have this peculiar property of permitting electric current to flow through them in one direction but not in the other. We do not know precisely how this control is accomplished but we have theories. It would not help our understanding of modern radio receivers, however, to enter at this point into a discussion of those theories.

42. Crystal Detectors

The crystal most commonly used for detectors is galena, a mineral compound consisting of lead and sulphur. Not every spot on the crystal, however, has this remarkable property of making the one-directional current. We must, therefore, use a fine wire to find the spots that will work. The symbol for the crystal detector is: 

43. Making Your Set Work

When you have hooked up your receiver with the crystal detector in series with the phones, you must move your fine wire (which is called a *catwhisker*) from spot to spot. When you find a spot where you hear a sound in the phones, leave the wire at that spot. You should avoid handling the crystal as the grease from your fingers will interfere with its sensitivity. If your crystal becomes dirty, wash it in carbon tetrachloride to remove any grease.

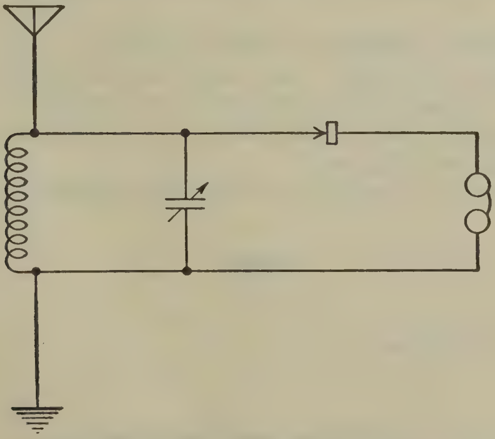


Figure 22. Diagram showing the complete crystal receiver. It makes no difference whether the catwhisker or crystal side of the detector is connected to the phones. This circuit will work.

SUMMARY

Your complete radio receiving set, in its simplest terms, then, must have these parts which we have discussed: an **aerial and ground**, a **tuner** (an **inductor** and a **condenser**), a **detector**, and a **reproducer** (phones). In the diagram of Figure 22 these parts are arranged in proper relationship to each other. If you understand the symbols and connect the parts of your set according to this arrangement, you should be able to hear speech and music through the earphones.

GLOSSARY

Alternating Current (A.C.): An electric current in which the electrons periodically reverse their direction of flow.

60-cycle Alternating Current: An alternating current that changes direction 120 times a second or 60 cycles a second.

Radio-frequency Alternating Current: An alternating current that changes direction thousands and even millions of times a second.

Catwhisker: The thin wire with which we hunt for a sensitive spot on the crystal.

Current, electric: The flow of electrons through a conductor.

Detector: An electrical gate or valve permitting the flow of electrons in one direction but not in the other.

Direct Current (D.C.): An electric current in which the electrons constantly flow in one direction.

Pulsating Direct Current: A direct current that periodically changes in strength.

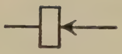
Electron: A minute, negatively charged particle.

Electron Theory: A theory which explains the nature of an electric current, as electrons moving through a conductor.

Galena: A mineral crystal, a compound of lead and sulphur, used as a detector in the receiving set.

Voltage: The electrical pressure that causes electrons to flow in a conductor.

SYMBOL

 Crystal detector.

QUESTIONS AND PROBLEMS

1. Briefly describe the electron theory.
2. At what rate does an electrical current pass through a conductor?
3. Describe direct current. Compare it with alternating current.
4. Give the relationship between the frequency and the cycles of an alternating current.
5. What is the frequency of alternating current in the home? How does its frequency compare with radio-frequency alternating currents?
6. What is the response of the diaphragm of a pair of earphones when radio-frequency alternating current is sent through the phones? Account for its behavior.

7. Describe the behavior of a pulsating direct current through a conductor.

8. Describe the action of a pulsating direct current which has been obtained from a radio-frequency alternating current by means of an electrical gate or detector, as the current passes into the phones.

9. What is the electrical action of a detector? Give two crystals used as detectors.

10. How do we manipulate a crystal used as a detector, and what must we do to take proper care of it?

CHAPTER 9

Wave Form

Problem 1: *How is the type of electric current shown by a graph?*

Problem 2: *What is meant by the "sine wave"?*

Problem 3: *What is a modulated radio wave?*

Problem 4: *In what form is the modulated carrier wave passed through the tuner, detector, and reproducer?*

Did you ever visit a sick friend in a hospital? Did he, perhaps, point to the chart hung at the foot of his bed and say, "This is my temperature chart"? You examined the chart and saw on it a wavy line going up and down several times and finally—we hope—leveling out to a horizontal line. You know, of course, that the temperature did not travel over this scenic-railway type of

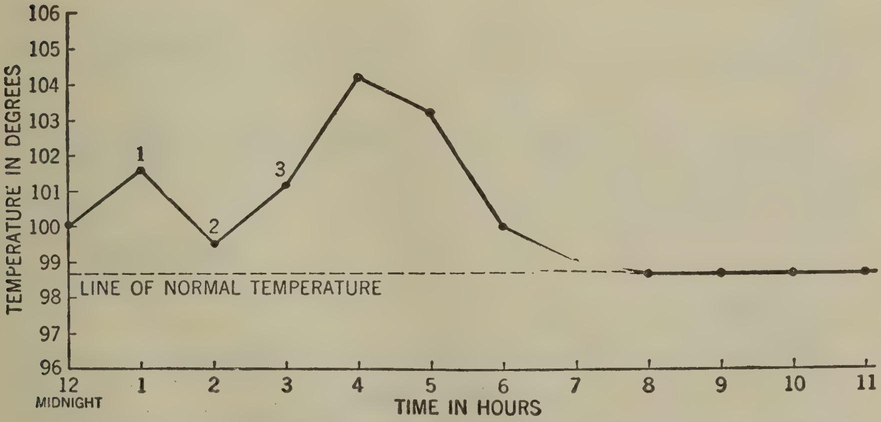


Figure 23. Temperature graph for your sick friend. Note that the vertical part shows the degrees of temperature while the horizontal part shows the time. By this means we can see what the temperature was at any particular time.

path. This chart was merely a picture or diagram which showed how high your friend's temperature was at any given time of the day. We call such a chart a *graph.*

44. Graphs

The word *graph* means a drawing or a picture. Many kinds of graphs are used in science, mathematics, and economics. The most common kind of graph attempts to show, by a line called a *curve,* the course of events when two different conditions are changing. In the graph, Figure 23, the two conditions are time and temperature. The hours are marked from left to right on the horizontal line in equal spaces. The degrees of temperature are marked on the vertical line with the lowest temperature at the bottom. The nurse reads the temperature of the patient each hour and makes a dot on the vertical line over the hour where the horizontal line from the observed temperature crosses it. For example, the chart shows that at 1 A.M. the patient's temperature was 101.8° (dot 1); at 2 A.M. the temperature was 99.5° (dot 2). Thus each dot is the temperature at a certain hour. When the points or dots are connected by a continuous line, the course of the fever is pictured. This line or curve is called here the temperature curve.

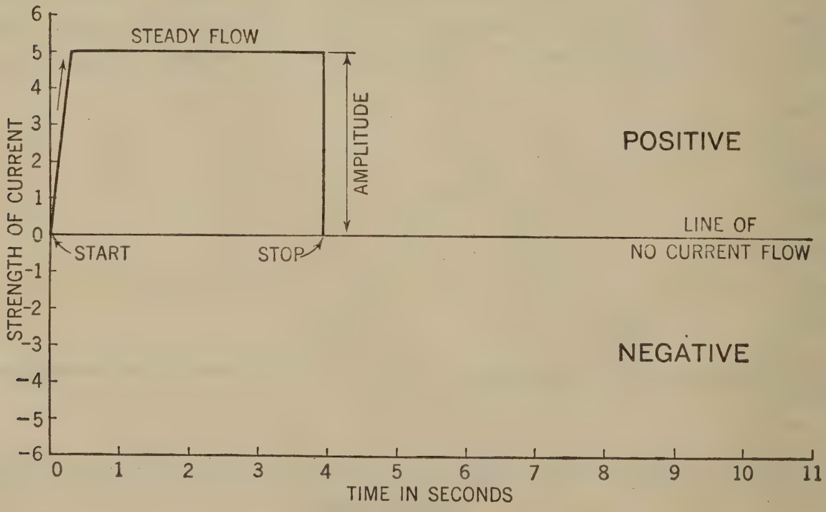


Figure 24. Graph showing curve or wave form of a steady direct current.

45. Graph of D.C. Flow

We can draw such a chart or graph to show how electric current flows. First we draw a horizontal line and call it the *line of no current flow.* When electric current flows in one direction we call it *positive* and picture its path above the line of no current flow. When it reverses itself and flows in the opposite direction, we call it *negative* and picture its path below the line of no current flow. Thus, the path of a direct current is entirely above that line. If the current is a steady direct current, the picture of its flow starts at the line of no current flow and very quickly rises above it to the maximum strength of the current (see Figure 24). It then continues to flow at the same rate, and we picture it as a straight horizontal line until the instant when the current is cut off. At that point, the line drops down to zero, the line of no flow. The line we draw picturing that flow of current is called the *curve* or *wave form.*

The strength of the current at any one instant of time is shown by the distance of the curve away from the line of no current flow at that instant (amplitude).

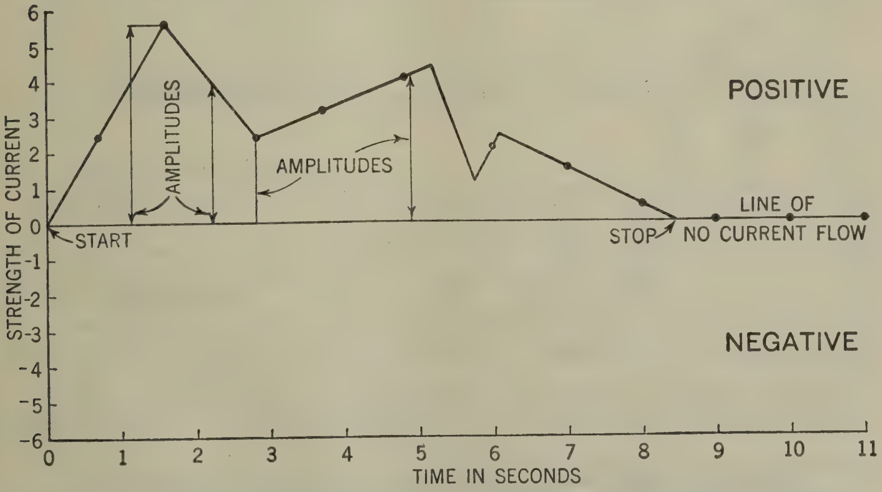


Figure 25. Graph showing curve or wave form of a fluctuating direct current. Note that the amplitude may assume different values at different times.

46. Fluctuating D.C.

A direct current may either be steady or fluctuating. If it is steady, the amplitude is constant while the current is flowing, as shown in Figure 24. In the case of a fluctuating direct current, the amplitude is different at different intervals of time, as shown in Figure 25.

Notice that in both Figures 24 and 25 the current is direct current, that is, it flows in only one direction. You can see this from the graphs by observing that in both cases the curves lie entirely above the line of no current flow.

47. The Sine Curve for A.C.

We can also picture the flow of an alternating current by means of such a graph. The current starts from zero and rises to a maximum flow in one direction. Still flowing in that direction, it starts to slow down until it again reaches the line of no current flow. Then it flows to a maximum in the opposite direction (below the line), and then slows down again until the zero line is reached. As you already know, the flow of current has gone through one cycle (see p. 45). Then it starts all over again.

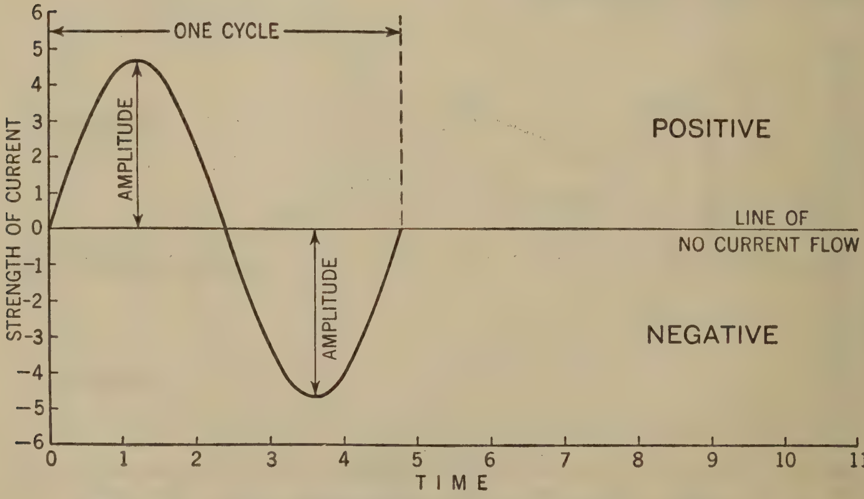


Figure 26. Graph showing curve or wave form of an alternating current. A curve whose amplitudes rise and fall in the smooth, even and regular glide pictured here is called a sine curve.

Note that during the first half of the cycle the amplitude increases from zero to maximum in a smooth, regular glide and then decreases to zero in that same, even way. The same thing occurs during the second half of the cycle (the bottom loop of the curve). A curve having this form is called a *sine curve* (Figure 26).

The flow of alternating current does not always describe a smooth sine curve. The rise from zero to maximum may be irregular and varied. The decrease from maximum to zero may be the same (Figure 27).

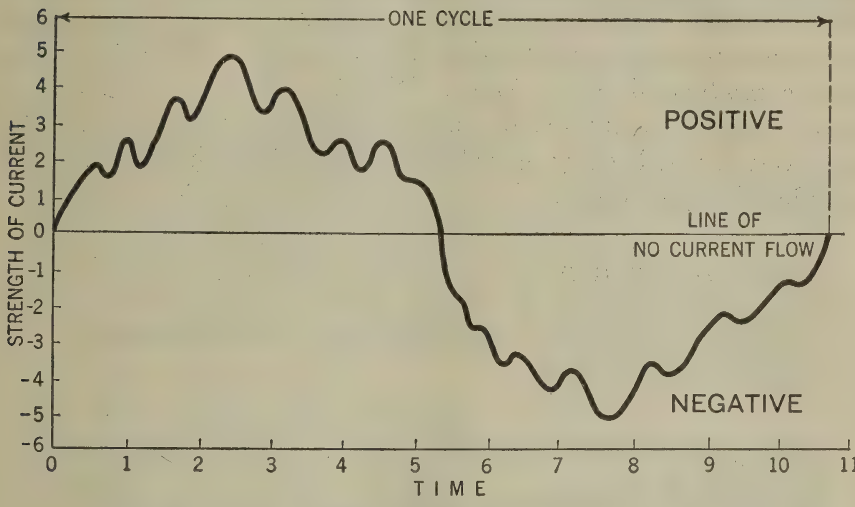


Figure 27. Graph showing curve or wave form of an alternating current. Notice that this curve is not smooth but irregular.

48. Radio Wave Forms

It would help you to better understand what takes place in your receiver, perhaps, if you were to examine the wave forms of the electrical currents flowing in the various parts.

Consider the wave form of the radio wave. It is the same as that of an alternating current, that is, it flows first in one direction and then in the other. Its range of frequency is from 10 kc. to 3,000,000 mc. per second. In the United States, standard broadcasting stations send out radio waves whose frequencies lie between 550 kc. and 1,600 kc. per second. This range is fixed by law and each station is given a definite frequency to which it must always keep its station tuned.

The radio wave may take several different forms. For the moment, we are interested in three of them. *First,* there is the wave whose form is that of a smooth sine wave and whose maximum amplitude is constant throughout the entire wave. Such a wave is called a *continuous wave*—also known as a *carrier wave.*

Second, there is the wave whose form is that of a smooth sine wave but with the maximum amplitudes of successive cycles decreasing gradually. Such a wave is called a *damped wave.*

Third, there is the wave whose form is that of a smooth sine wave but with the maximum amplitudes of successive cycles varying irregularly. This wave form is obtained by impressing upon a continuous wave a fluctuating direct current. We call such a wave a *modulated carrier wave.* We say that the continuous or carrier wave is modulated by the fluctuating direct current. The radio waves which carry speech and music through the ether are modulated carrier waves.

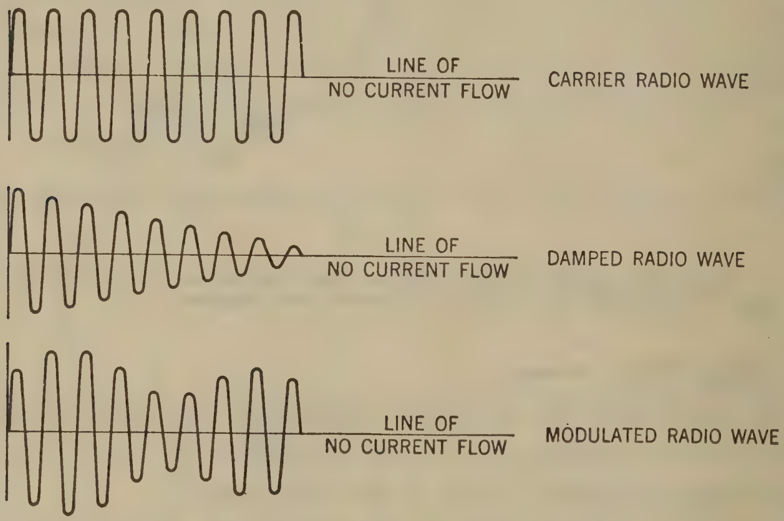


Figure 28. Graphs showing the wave forms of a continuous radio wave, a damped radio wave and a modulated radio wave. Note that in all three waves shown here the frequencies are the same. It is only the amplitudes that vary.

49. How the Modulated Wave Is Produced

To understand the method by which a fluctuating direct current modulates the carrier wave, examine Figure 29. First of all, sound striking the microphone at the broadcasting station sets up a fluctuating direct current. Meanwhile, in another part of the transmitting set, a continuous or carrier wave has been generated. Assume the frequency of this carrier wave to be 500 kc. per second.

The fluctuating direct current is now mixed with the carrier wave. The result is the modulated radio wave whose frequency is 500 kc. per second, but whose amplitudes correspond to the form of the fluctuating direct current.

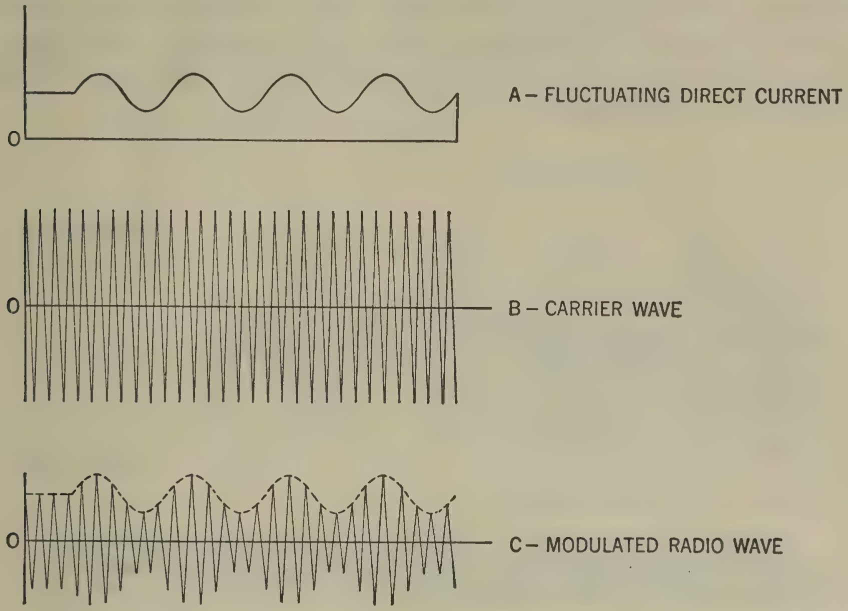


Figure 29. Graph showing how a fluctuating direct current from the microphone modulates the carrier wave to produce the modulated radio wave which is broadcast by the transmitting station.

In this way, we modulate the carrier wave by the electric currents set up by sound waves hitting the microphone at the transmitting station. The modulated radio wave is broadcast by the transmitter. It is the task of the radio receiver to collect this modulated radio wave and to separate the carrier wave from the electric currents impressed on it by the microphone. These impressed currents are the currents that operate our phones and through their action we reproduce the original sound waves.

50. Wave Form—Aerial-Ground System

You have already learned (p. 19) that when the modulated radio wave passes across the aerial of your receiving set it sets up in the aerial-ground system an electrical pressure or voltage that causes an electric current to flow in that system. The greater the pressure, the greater the flow of current. This flow of current, therefore, conforms to the electrical pressure, which in turn conforms to the modulated radio wave. You can see, therefore, that the flow of current in the aerial-ground system will correspond to the wave form of the modulated radio wave. The current that flows in the aerial-ground system, then, is alternating current whose frequency is the same as that of the modulated radio wave. The amplitudes, too, will be the same as the amplitudes of the modulated radio wave.

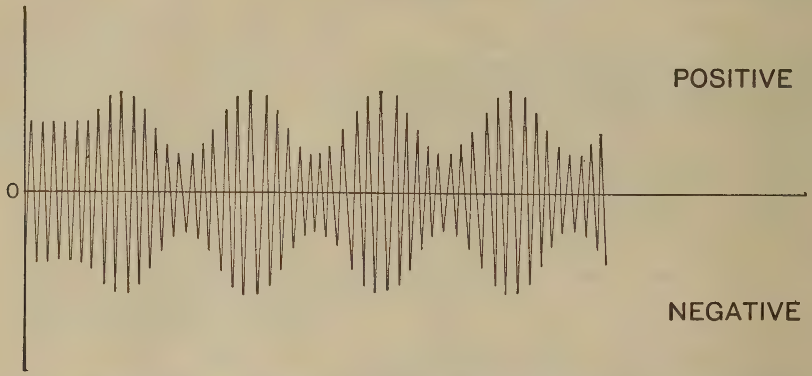


Figure 30. Wave form of alternating current set flowing in the aerial-ground system when the modulated radio wave shown in Figure 29-C passes across the aerial of the receiving set.

51. Wave Form—the Tuner

Electric current flowing in the aerial-ground system, you will recall, sets an electric current flowing in the tuning circuit of your receiver. This current takes the same wave form as that in the aerial-ground system, which in turn has taken the same wave form as that of the modulated radio wave. The current flowing in the tuner, then, is alternating current having the same frequency and amplitudes as the current flowing in the aerial-ground system.

52. Wave Form—the Detector

The crystal detector, you will remember, permits electric current to flow through it only in one direction. See if you can picture what happens to an alternating current as it attempts to flow through such a crystal.

First, the positive half of the cycle approaches the crystal and finds the "gate" wide open. That is, the positive part of the cycle can pass through the crystal. When the current reverses itself, the gate is shut and no current can flow through. The current thus flows through with all its variations as long as it is going in one direction—as long, that is, as it does not go below the line of no current flow of our graph (see Figure 31). Everything in the graph below the line of no current flow is wiped out.

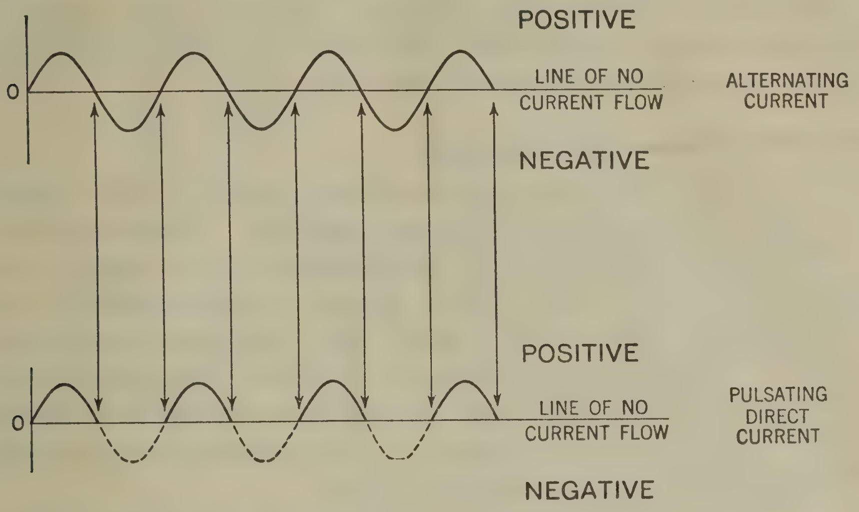


Figure 31. Graph showing how the crystal detector changes alternating current into pulsating direct current. The negative halves of the cycles which were stopped by the crystal detector are shown by the dotted lines.

Our current now consists of a series of direct-current pulses, separated by gaps of no current flow that represent the negative halves of the cycles which were stopped by the crystal. This is what is meant by a pulsating direct current.

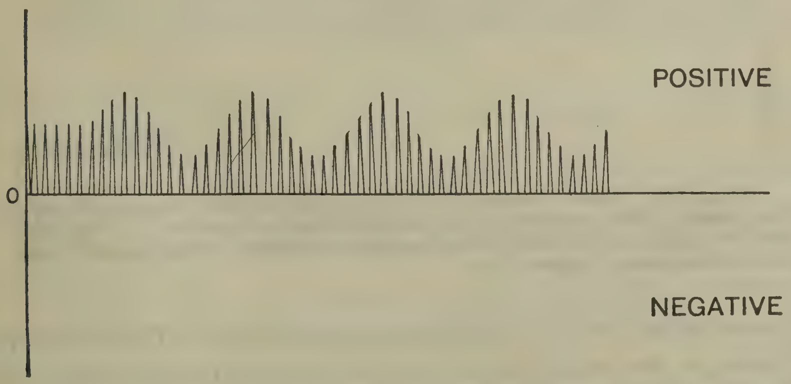


Figure 32. Graph showing flow of pulsating direct current through the crystal detector. Note the action of the detector.

We can now see what will happen to the alternating current of our tuner when it reaches the crystal detector. The current is changed from an alternating to a pulsating direct current and the bottom halves of the cycles in the curve are wiped out. This, then, is what we mean by detection. The wave-form picture is the same as that for the tuner, except that the half below the line of no current flow is eliminated (see Figure 32).

53. Wave Form—the Reproducer

The current flowing out of the crystal detector is now a series of direct-current pulses of varying amplitude. These variations of amplitude correspond to the curve described by the current that was set flowing by sound waves striking the microphone at the broadcasting station. If we again take our hypothetical radio station broadcasting at a frequency of 500 kc. per second, each such direct-current pulse lasts for one one-millionth of a second and is separated from its neighbor by an interval of one one-millionth of a second when no current flows.

As you already know, the diaphragms of the phones cannot respond to a pulse of such short duration, but since each pulse is flowing in the same direction, a series or train of such pulses makes its effect felt. The result on the phones then, is the same as if a continuous, but varying, direct current, equal to the average of all these pulses, were to pass through the coils. This effect can be shown on the graph by joining the peaks of these pulses with a continuous line. We call such a line the *envelope* of the wave

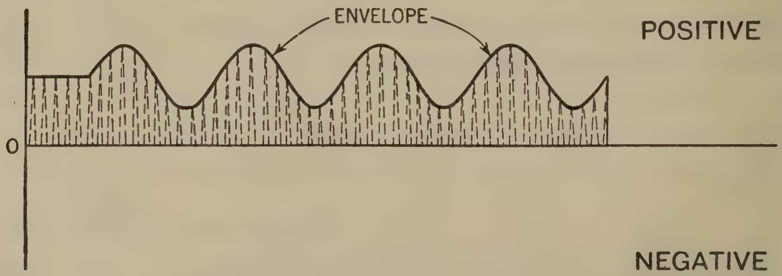


Figure 33. Graph showing flow of fluctuating direct current through the phones. This current flow is indicated by the envelope. Note that the envelope has the same shape as the fluctuating direct current from the microphone in Figure 29-A.

(see Figure 33). You will notice that this envelope has the same shape as the current set up by the microphone at the broadcasting station. We have now succeeded in making the carrier wave take the form of the modulating current; and it is this modulating current, acting through our phones, that reproduces the sound originally created at the broadcasting station.

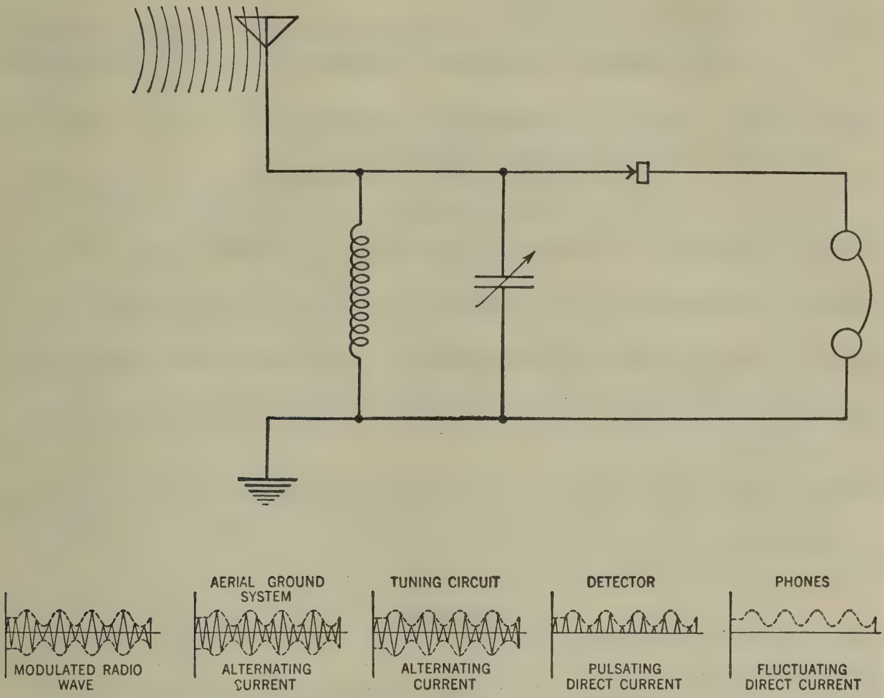


Figure 34. Hookup of complete crystal receiver showing wave forms of electric currents flowing in the various parts.

SUMMARY

1. A **graph** is a picture.
2. Graphs in scientific work usually show relations between two or more **variable** quantities.
3. The line which pictures the course of any event in a graph is called a **curve.**
4. The **sine curve** is the graph which shows the wave form of an alternating current.
5. Three forms of radio waves must be distinguished; **carrier** or **continuous** wave, **damped** wave, and **modulated carrier** wave.

GLOSSARY

Amplitude: In a graph picturing the flow of electric current, the amplitude is the distance a point on the curve is away from the zero line (or line of no current flow) at any particular instant.

Envelope: The line joining the peaks of the curve lying on one side of the zero line of the graph.

Fluctuating Direct Current: Direct current that is constantly changing in strength or amplitude.

Graph: A diagram that pictures the instantaneous relationship between two varying factors, for example, temperature at a certain instant of time.

Modulation: The act of varying the amplitudes of a carrier wave by means of a current of lower frequency.

Sine Curve: A graph indicating the smooth variations of current flowing in an alternating-current circuit.

Wave, Carrier: A continuous wave at radio frequency (very high frequency).

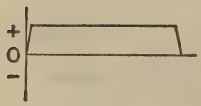
Wave, Continuous: A wave which has an equal peak amplitude for all cycles.

Wave, Damped: An alternating-current sine wave whose peak amplitude gradually and continuously decreases for each cycle.

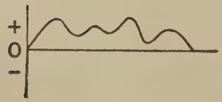
Wave Form: A graph showing changes of direct- and alternating-current flow.

Wave, Modulated Carrier: A carrier wave whose amplitude is continuously varied as the result of mixing with a current of lower frequency.

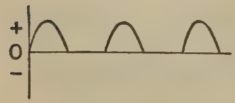
SYMBOLS



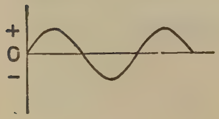
Graph showing a steady direct current.



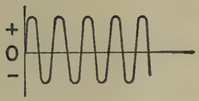
Graph showing a fluctuating direct current.



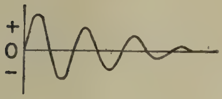
Graph showing a pulsating direct current.



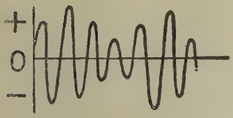
Graph of a sine curve (alternating current).



Graph of a carrier wave.



Graph of a damped wave.



Graph of a modulated carrier wave.

QUESTIONS AND PROBLEMS

1. What does a graph actually show?

2. Draw a graph of an alternating-current sine wave; of a steady direct current; of a pulsating direct-current.

3. What would we know if we knew the amplitude of a sine wave indicating alternating current at any one instant?

4. Draw the picture of an alternating current whose graph is not a sine curve.

5. In what particular respect are radio broadcasting stations different?

6. Give three forms that a radio wave may take and make a graph of each.

7. Describe briefly how the modulated radio wave is produced.

8. Describe the relationship between the modulated radio wave and the current in the antenna-ground system.

9. Describe the wave form of the modulated carrier after it has gone through the crystal detector. Draw a graph of it.

10. Describe what is meant by detection.

11. Why cannot phones react to the current produced in the aerial-ground system while they do respond to a detected radio-frequency current?

12. Draw the envelope of any modulated radio-frequency current graph. What does it represent?

CHAPTER 10

The Antenna Coupler

Problem 1: *What are the faults of a tuner having but one coil?*
Problem 2: *What are the principles of a transformer?*
Problem 3: *How do we use a transformer to correct the faults of our tuner?*

In continuing our study of radio, we shall follow the plan of pointing out certain faults and shortcomings of our simple sets. Then we shall explain the various methods of correcting these faults.

54. Faults of the Tuner

Let us study the tuner. The function of the tuning circuit is to select the wave of desired frequency and reject all others. While the tuner you built does this job fairly well, it occasionally fails to separate two stations completely, especially if these stations are quite powerful, close to your home, and not much different in frequency. You then hear a fairly loud broadcast from one station and in the background, although a good deal weaker, the *signal* or program from another station.

Theoretically, the tuning circuit should pass only one frequency. But because some resistance to the flow of current is always present in the circuit, other frequencies creep in. When this resistance becomes too great, two stations may be heard at the same time.

55. Why We Hear Two Stations

We can draw a picture to represent this situation. In Figure 35, we have assumed that the station desired has a frequency of 1,000 kc. Let us assume also that there is no difference in the distance or power of the stations. Along the horizontal line we have indicated successive frequencies from 960 kc. to 1,040 kc.

Along the vertical line we have indicated the loudness of the signal received. The amplitude of the curve at any point then represents the loudness with which a signal of that particular frequency will be heard when your tuner is set for 1,000 kc. If the amplitude at that frequency rises above the line marked "audibility level," the signal will be heard in the earphones. If it does not reach that level, the signal will be unheard and therefore will not interfere.

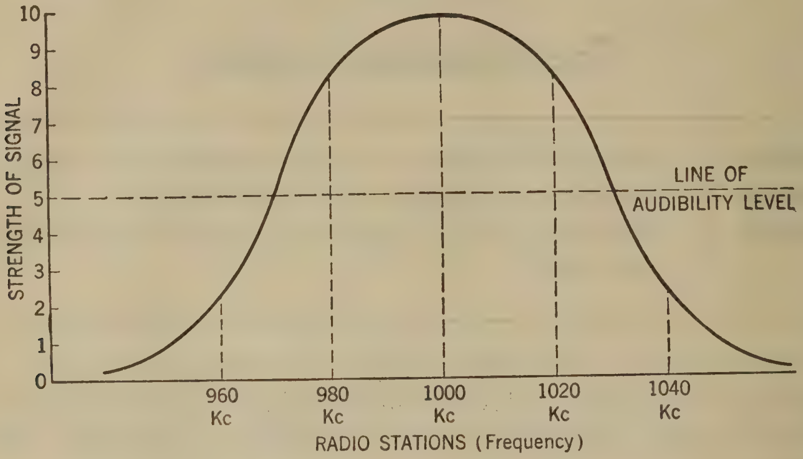


Figure 35. Graph or tuning curve showing what happens when a receiver tunes broadly. Note that unwanted radio stations at 980 kc. and 1020 kc. come in well above the line of audibility level. This means that three stations will be heard at the same time.

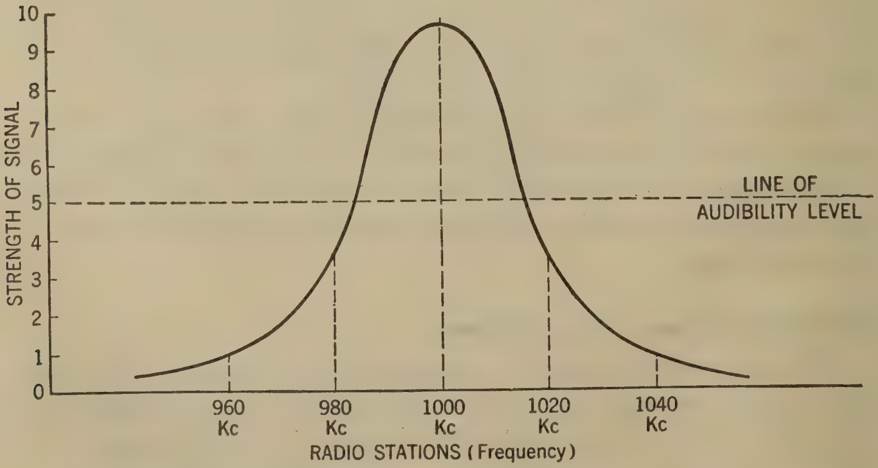


Figure 36. Graph or tuning curve for a sharply tuning receiver. Note that all unwanted radio stations fall below the line of audibility level.

You will notice from the graph in Figure 35 that this particular tuner will permit three stations to be heard simultaneously, the one we want at 1,000 kc. and two unwanted ones at 980 kc. and 1,020 kc. We say that such a set *tunes broadly.* We can remedy this by redesigning our tuner so it will have a tuning curve that will correspond to Figure 36.

Note that now the amplitude of every station except the one desired falls below the line of audibility level. Such a set, we say, *tunes sharply.*

56. Reducing Resistance in the Tuner

In practice, we accomplish the desired change by reducing the resistance of the tuning circuit.

Examine again the circuit diagram of your crystal receiver in Figure 22. You will notice that the aerial-ground system and the tuning circuit follow a common path through the tuning coil. This means that the resistance of the aerial-ground system is added to the resistance of the tuner.

It is quite possible to reduce the resistance of the tuning circuit to a very small value. But the resistance of the aerial-ground system, of necessity, is quite large. It includes the resistances of the aerial, of the lead-in wire, of the ground, and of the various connections. It is this resistance, therefore, that causes our set to tune broadly and bring in more than one station at a time. It would be ideal if we were able to transmit to the tuner the electrical currents flowing in the aerial-ground system and yet be able to keep out of the tuning circuit the aerial-ground system's resistance.

57. What Is a Transformer?

To see how this undesirable resistance is kept out, you must first learn what we mean by a *transformer.* You already know that when an electric current flows through a coil of wire it sets up a magnetic field around this coil. When this magnetic field cuts across a conductor it sets up an electrical pressure or voltage which in turn sets a current flowing.

We can have this magnetic field cut across a conductor in two ways. We can either have a stationary magnetic field set up by a steady direct current flowing through the coil and use a moving conductor, or we may have a moving magnetic field and a stationary conductor. This moving magnetic field can be produced when either a fluctuating direct current or an alternating current passes through the coil. The magnetic field is built up and collapsed in step with the variations of current in the coil.

In the transformer we have two stationary coils. We call one the *primary* and the other the *secondary*. We pass a fluctuating direct current or an alternating current through the primary coil. This current causes the magnetic field around the primary to fluctuate in step with it. This fluctuating magnetic field, cutting across the turns of the secondary coil, sets up a fluctuating electrical pressure that in turn causes an alternating current to flow in the secondary. This alternating current corresponds in form to the fluctuating direct current or the alternating current in the primary.

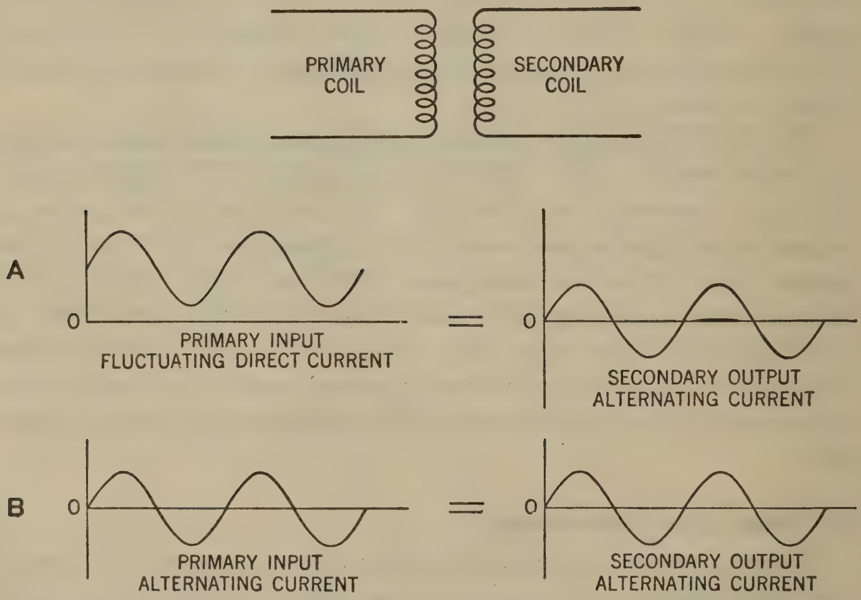

PRIMARY COIL
SECONDARY COIL
A
0
PRIMARY INPUT FLUCTUATING DIRECT CURRENT
=
0
SECONDARY OUTPUT ALTERNATING CURRENT
B
0
PRIMARY INPUT ALTERNATING CURRENT
=
0
SECONDARY OUTPUT ALTERNATING CURRENT

Figure 37. Diagram showing that if a fluctuating direct current (A) or an alternating current (B) be sent into the primary of a transformer, the output from the secondary coil is always an alternating current.

58. Step-up and Step-down Transformers

Here is another interesting thing about a transformer. As you know, the fluctuating magnetic field cutting across the turns or loops of wire of the secondary coil sets up an electrical pressure or voltage in those loops. If we have more loops in the secondary coil than in the primary coil we have a greater total voltage in the secondary. If we have fewer loops in the secondary than in the primary we have a smaller total voltage in the secondary coil. Thus by varying the ratio between the number of turns of wire in the primary and secondary coils we can get a greater or smaller voltage in the secondary coil. For example, if the secondary coil has twice the number of turns that are in the primary coil, the voltage in the secondary will be twice that in the primary coil. We call such a transformer a *step-up transformer.* If, however, the secondary winding has half the number of turns that are in the primary winding, the voltage set up in the secondary winding will be half the voltage in the primary. We call such a transformer a *step-down transformer.*

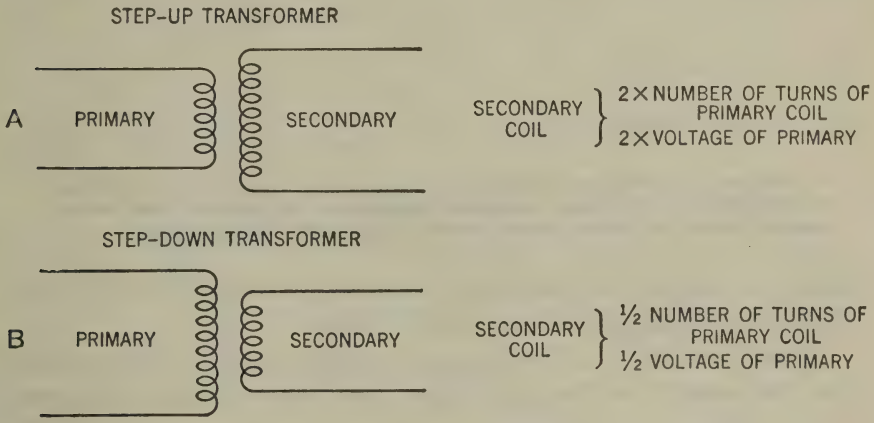


Figure 38. A—Step-up transformer. B—Step-down transformer.

59. The Antenna Coupler

Now see how what you have learned about a transformer fits into our radio receiver. You will recall that we were seeking a method for transferring the electric current from our aerial-ground system to the tuning circuit and, at the same time, for keeping out the aerial-ground system's resistance. The transformer is the answer. If we make the tuning coil the secondary of our transformer and hook the primary into the aerial-ground system, we have solved our problem. Now the current is passed on and the resistance of the aerial-ground system is kept out.

As a matter of fact, by making our primary winding with fewer turns than the secondary (the tuning coil), we actually get a step-up effect and we get a greater voltage in the tuning circuit than in the aerial-ground system.

Such a transformer used at this point is called an *antenna coupler* or transformer. Through its use we obtain sharper tuning, that is, we are able to keep out unwanted stations, since we have reduced the resistance of our tuning circuit.

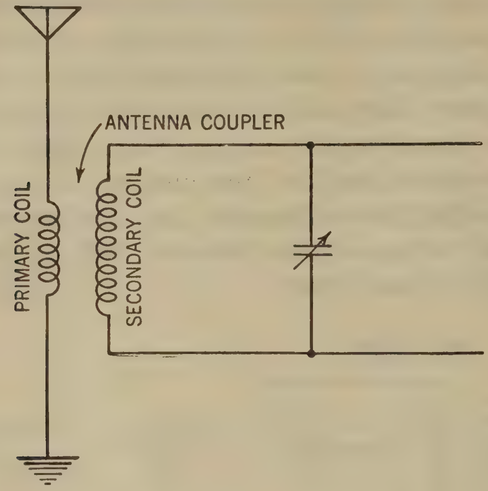


Figure 39. Diagram showing how an antenna coupler or transformer is connected in the radio receiver. Note that the path of the aerial-ground system no longer passes directly through the tuning circuit.

To make such an antenna coupler, all you have to do is to wind upon the same tube that you have your tuner coil an additional

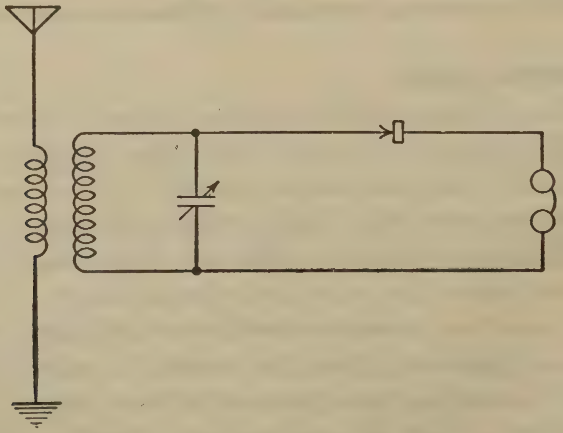


Figure 40. Improved crystal receiver, using an antenna coupler. This set will tune sharper than that of Figure 22.

winding of about 15 turns of wire (the primary winding). Separate the two windings about ⅛ in. Connect the lead-in from the aerial to one end of the primary winding and the ground to the other. Try reversing the aerial and ground connections to this winding to obtain best results. Your improved crystal receiver will now appear as in Figure 40.

SUMMARY

1. One of the faults of the **tuner** consisting of a single coil, is that it does not sharply separate different stations.

2. This fault may be partially corrected by a **transformer.**

3. The transformer consists of two coils unconnected but wound upon the same core. In such a device, the magnetic field created by a current in one coil transfers the energy to the other coil. In the second coil the fluctuation in the current induced therein will follow the pattern of the current in the first coil.

4. The voltages in the primary and secondary coils have direct ratio to the ratio of the number of turns of wire in the coils.

5. An **antenna coupler** is a transformer having the primary in the antenna circuit and the secondary in the tuner circuit.

GLOSSARY

Antenna Coupler: An air-core transformer used to couple the energy from the aerial-ground system to the tuning circuit.

Resistance: The opposition a substance offers to the flow of electric current through it.

Primary: The input coil of a transformer.

Secondary: The output coil of a transformer.

Transformer: An electrical device consisting of two separate coils, insulated from each other, used to transfer electrical energy from one circuit to another.

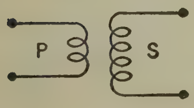
Transformer, step-down: A transformer which develops a lower voltage across the secondary than the voltage impressed across the primary.

Transformer, step-up: A transformer which develops a higher voltage across the secondary than the voltage impressed across the primary.

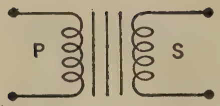
Tuning, broad: The simultaneous reception of several stations in a radio receiver.

Tuning, sharp: The ability of a radio set to receive one station only at a time.

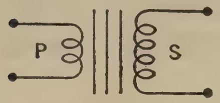
SYMBOLS



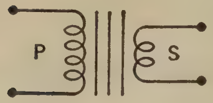
Transformer with air for a core, such as the antenna coupler.



Transformer wound on an iron core.



Step-up iron-core transformer.



Step-down iron-core transformer.

QUESTIONS AND PROBLEMS

1. What is the effect of resistance in a tuning circuit?
2. What response will be obtained from a receiver that tunes broadly?
3. What practical measure may we use to remove the resistance of the aerial and ground from the tuning circuit?
4. Under what circumstance will a moving magnetic field be produced about a stationary current-carrying conductor?
5. Describe the structure and operation of a transformer.
6. How may the voltage in the secondary of a transformer be made to vary from the voltage impressed across the primary?
7. Describe the type of transformer used as an antenna coupler.
8. Draw a diagram of an antenna coupler in a receiver circuit.
9. Draw a diagram of a complete crystal receiver using an antenna coupler.

CHAPTER 11

Electron Flow in the Aerial-ground System

Problem 1: *How does a dry cell produce an electromotive force?*
Problem 2: *What are two kinds of alternating-current generators?*
Problem 3: *What kind of currents are produced in the aerial-ground system by radio waves?*

You have learned in our previous study that an electric current consists of a flow of electrons through a conductor forming a circuit. Let us see if this theory can give us some new light upon what happens in a radio receiver.

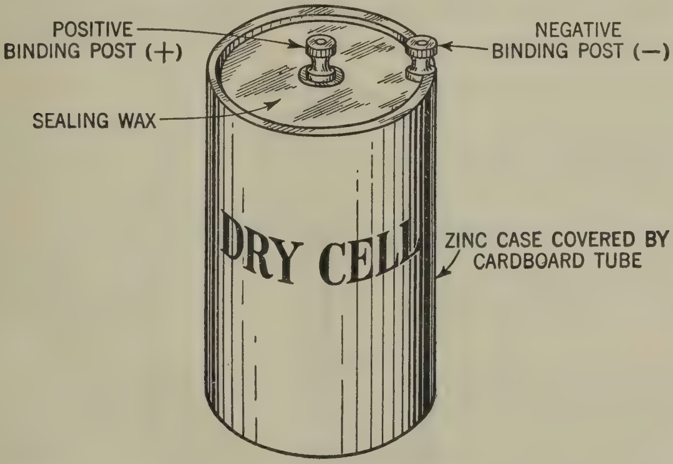

POSITIVE BINDING POST (+)
NEGATIVE BINDING POST (−)
SEALING WAX
DRY CELL
ZINC CASE COVERED BY CARDBOARD TUBE

Figure 41. The dry cell.

60. A Dry Cell Is an Electron "Pump"

Look at a dry cell. You will notice that it is a can made of zinc, closed at one end. The other end is sealed with some insulator such as sealing wax or pitch. In the center of the sealing wax you will notice a binding post on a carbon rod. This post may be marked POSITIVE or +. At the same end of the cell, but fastened to the zinc, is a second binding post which may be marked NEGATIVE or —. The inside of the can is filled with certain chemicals.

The carbon rod in a dry cell is called the *positive pole* and the zinc is called the *negative pole.* It is customary to name the pole from which electrons leave the cell the negative pole. In general the terminals of a battery or cell are called *poles* or *electrodes.*

You may not have heard it, but a dry cell is sometimes called an electron "pump." The chemical action inside the cell builds up a pressure of electrons. This pressure exists, even when no electrons are flowing. You can understand this if you think of a water faucet. The water behind the faucet is under a pressure even when the faucet is closed and no water is flowing. When the faucet is opened the water flows out.

So it is with the electrons in the dry cell. They accumulate at the negative pole and thus produce a pressure. When a path is furnished them by connecting a conductor between the negative and positive posts of the dry cell, electrons will flow out of the negative post of the cell, through the conductor and back into the positive post of the cell.

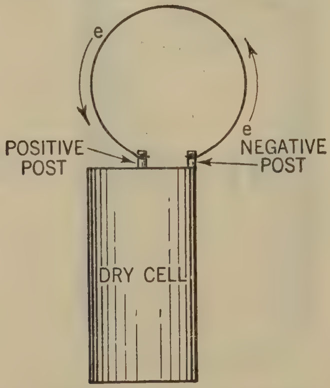


Figure 42. The dry cell is a sort of pump sending electrons streaming from the negative post to the positive post when a path is furnished.

61. Electromotive Force (E.M.F.)

The dry cell piles up electrons at the negative post and creates a deficiency of electrons at the positive post. *When electrons are given a path to travel, they will always move from the place where* *they have been piled up to a place where there is a deficiency.* When electrons are in excess at a point we say that point has a *negative charge.* If given a path, then, electrons will flow from a point with a negative charge to a point with a positive charge. In other words, *electromotive force* (E.M.F.) is the tendency of electrons to move from a place where there are many electrons to a place where there are fewer electrons.

If two or more dry cells are connected in *series,* that is, with the positive post of one connected to the negative post of the other, the effect is as if two or more pumps were connected together. The E.M.F. (or voltage) of the two cells is equal to the sum of their voltages. This increased E.M.F. causes more electrons to flow through any given circuit than does one cell.

62. Like Charges Repel; Unlike Charges Attract

Another thing to remember about electrons is that they repel each other. So while electrons will be attracted to a point with a positive charge (a deficiency of electrons), they will be repelled from a point with a negative charge (an excess of electrons).

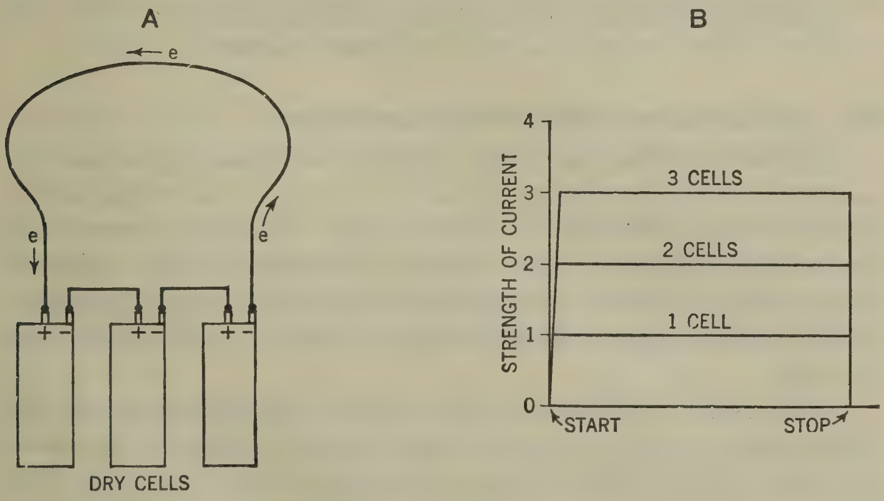


Figure 43. **A—Three dry cells connected in series.**
B—Graph showing flow of current from 1 dry cell, 2 dry cells, and 3 dry cells respectively.

Since a dry cell can generate only a direct current, we have been considering the flow of electrons in one direction only. This kind of flow is called a *direct current* (*D.C.*). But if a pump could be devised that would cause electrons to flow first in one direction and then in the other, the current then would be called *alternating current* (*A.C.*).

63. A.C. Generators

We have no such battery, but we have another kind of "pump" to make current flow first in one direction and then in the other. It is called an *alternating-current* (*A.C.*) *generator*. One form is the tremendous machine called a dynamo, at the power house that supplies the current for our electric lights and electrical implements. The current is usually produced by passing conductors through magnetic fields. Each complete movement of a conductor through a magnetic field is called a cycle and in each cycle the direction of the current changes twice. The stream of electrons pumped out by most A.C. generators changes its direction of flow 120 times in a second. Hence we call the electric current from such a generator a *60-cycle alternating current.*

Another modern pump to produce alternating current is the marvelous device called the *radio tube.* At the broadcasting station one of these radio tubes sends out a stream of electrons which changes its direction of flow millions of times a second! We call such an electric current a *radio-frequency alternating current.*

64. A.C. Currents in the Aerial-ground System

By this time you know that the radio wave passing across your aerial causes an alternating current to flow up and down the aerial-ground system. The radio wave sets up an electrical pressure that causes the electrons to flow through the circuit. When electrons move back and forth through a circuit we say that they *oscillate.* See if you can picture how this takes place, by referring to Figure 44.

Here is the explanation. The radio wave, moving across the aerial-ground system, sets up for an instant a negative charge on the aerial and a positive charge on the ground of the system. The electrons, *which are present in the system at all times,* are set flowing *down* the aerial-ground system, as shown by the symbol:

e
↓

These electrons move through the aerial wire, then through the lead-in wire, then through the primary of the antenna coupler and into the ground. We show this flow on the graph in Figure 44-B.

The curve starts from point *A* on the line where the electrons are at a standstill and gradually increases its amplitude (the rate of electron flow), until at *B* the electrons are flowing at their maximum rate. Then these electrons start to slow down, still flowing in the original direction, until they reach a standstill at point *C*.

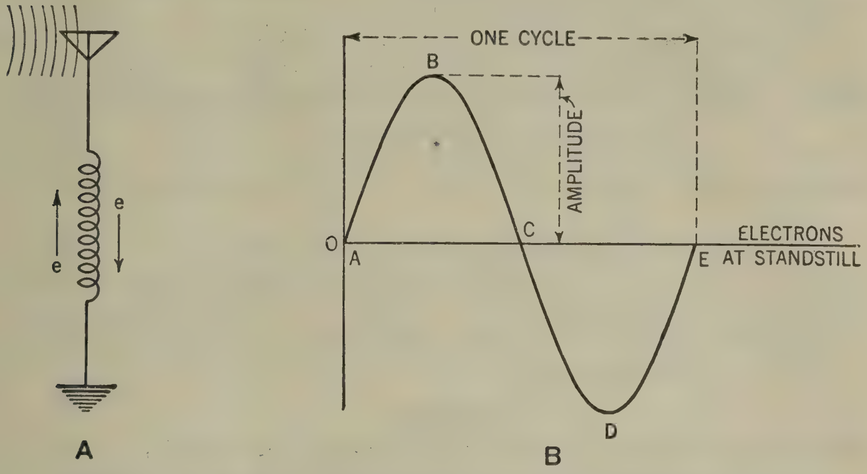


Figure 44. **A—Electrons flow up and down the aerial-ground system. B—Graph showing one cycle of current flow in the aerial-ground system.**

The radio wave has now reversed the direction of its electrical pressure. There is a positive charge on the aerial and a negative charge on the ground of the aerial-ground system. The electrons now change the direction of flow and stream *up* the system from the ground.

On the graph this direction change is shown where the curve starts its bottom loop. The electrons, moving in the reversed direction, now increase their rate of flow until the rate reaches its maximum at point *D* on the curve and then slows down to a standstill at point *E*.

The electron flow has gone through one cycle. In one second there may be millions of such cycles, corresponding to the frequency of the radio waves. We cannot show more than a few in a graph, but we plan the graph so that it shows the frequency by the time intervals along the horizontal line. The amplitude of each of the graph loops, too, corresponds to the amplitude of each loop in the current generated by the radio wave, as you have learned in Chapter 9.

SUMMARY

Try to read the following summary by supplying the right words for the blank spaces. *Do not write in the book.*

1. In the common dry cell, the outer can is made of (1) and the binding post on this electrode is marked (2) because electrons (3) the cell at this point. Another name for an electrode is (4) . The initials E.M.F. stand for (5) (6) (7) , which results from the piling up of (8) and their tendency to flow through a (9) to a place where there are (10) (11) s.

2. Two devices for producing alternating currents are the (12) and the (13) . When an alternating current changes direction 120 times per second it is called a (14) cycle alternating current.

3. Radio-frequency alternating currents may change directions (15) time per second.

GLOSSARY

Alternating Current: A current that changes its direction of flow in a circuit because of the changing polarity of the applied voltage.

60-cycle Alternating Current: An alternating current that reverses its direction of flow through a circuit 120 times a second.

Radio-frequency Alternating Current: Alternating current that makes thousands or millions of changes in the direction of current each second.

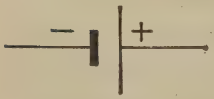
Cell: A chemical device used to generate an electron pressure or voltage.

Negative Charge: A region where there is an excess of electrons as compared with other regions.

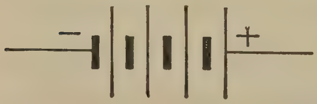
Pole (or **electrode**)**:** Terminal of a cell or battery through which electrons leave or enter.

Series Connection of Cells: Cells connected from + to — to + to —, and so on, to supply a higher total voltage than that of any single cell.

SYMBOLS



A cell.



Several cells in series.

QUESTIONS AND PROBLEMS

1. What direction will electrons always take in a circuit?

2. What is the behavior of electrons toward positive charges? Toward other negative charges?

3. What is the effect on the voltage of connecting several cells in series?
4. What type of current can be furnished by a dry cell?
5. Describe by a graph the changes occurring in an alternating current.
6. Give two methods of creating an alternating current on a practical basis.
7. What are the characteristics of a 60-cycle alternating current?
8. Under what conditions are electrons said to oscillate?
9. Describe the oscillations set up by radio waves in the aerial-ground system of a receiving set.

CHAPTER 12

Electron Flow in the Tuning Circuit

Problem 1: *How are currents induced in conductors?*
Problem 2: *What is the explanation of "charging" and "discharging" a condenser?*
Problem 3: *What is meant by self-induction?*
Problem 4: *How are the oscillations of the tuning circuit produced?*

We have just learned that the radio wave sets our electrons moving up and down the aerial-ground system. We now want to see the effects of this alternating current upon the other parts of our receiver.

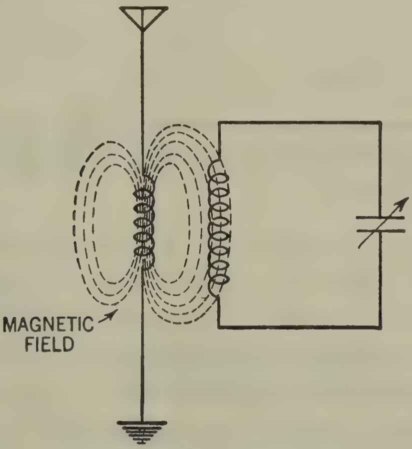


Figure 45. Diagram showing how a magnetic field around the primary of the antenna coupler cuts across the turns of the secondary.

65. Why Induction Occurs

First of all it should be recalled * that (a) every electric current is accompanied by a magnetic field and (b) when the lines of force of a magnetic field cut through a conductor or are cut through by a moving conductor, or even when there is any fluctuation in a magnetic field near a conductor, the result is an induced alternating current in the conductor.

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* At this point the main principles of the induction coil and the methods of producing an induced current should be reviewed or demonstrated. (Chap. 32, Vol. II.)

Our antenna coupler is a combination of two unconnected coils so related that any alternating or fluctuating current in either one will set up, by induction, an alternating current in the other. The relationship of electromotive force, current, and rate of change, in one such induction coil, is known as *inductance,* or in the case of two coils coupled, as *mutual inductance.* (Chap. 32, Vol. II.)

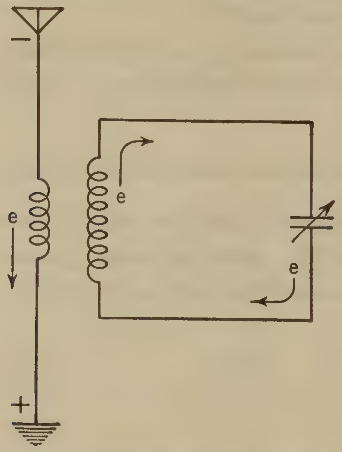

Figure 46. Diagram showing electrical charges and direction of electron flow in the aerial-ground system and tuning circuit during a half cycle of current flow. During the next half cycle, the charges and flow of electrons are reversed.

Here we have an explanation of how the electrical energy of the aerial-ground system is transferred to the tuning circuit through the antenna coupler. The sequence of events is: (1) The radio wave sets up an alternating current in the aerial-ground system, and especially in the primary coil of the antenna coupler. (2) This alternating current is accompanied by an alternating magnetic field. (3) The lines of force of this magnetic field cut through the conductors in the secondary coil of the antenna coupler. (4) Alternating currents in step with the radio waves are induced in the secondary coil. (5) These alternating currents, of radio frequency, are transmitted through all parts of the tuning circuit. The frequency of the current set flowing in the tuning circuit is the same as that in the aerial-ground system. The variations in amplitude of each cycle likewise follow the variations in amplitude of the current in the aerial-ground system.

Now let us examine the electron flow in the tuning circuit. You will recall that this circuit consists of a condenser and inductance connected together. We will examine each part separately, with special attention to the behavior of the electrons.

THE CONDENSER

66. Charging and Discharging a Condenser

A condenser consists of two or more metal plates (or conductors) separated by a dielectric (or insulator). A conductor is a substance that permits electrons to flow through it quite easily. An insulator is a substance that does not permit electrons to flow through it readily.

Now obtain a condenser whose capacity is about 1 microfarad (1 μfd.) and connect it to a 45-volt battery for a few seconds. Disconnect the battery. By means of a piece of wire, connect one plate of the condenser to the other. You will notice a spark jump from the end of the wire to the second plate of the condenser just as you are about to touch them together.

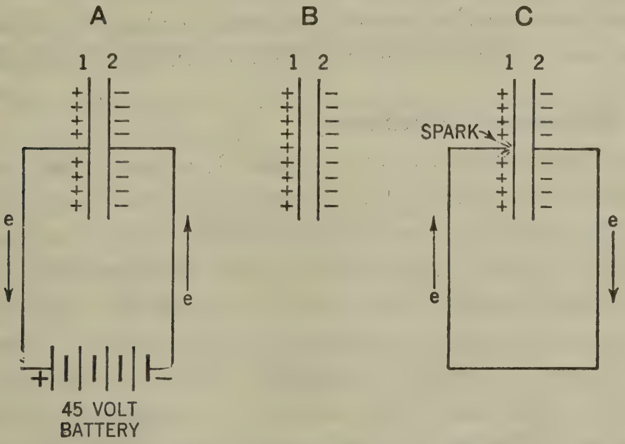

Figure 47. A—Charging a condenser.
B—A charged condenser.
C—Discharging a condenser.

67. Behavior of Electrons

This phenomenon is explained as follows: When you connected the battery to the condenser as in Figure 47-A, electrons were pumped onto plate 2 of the condenser from the negative post of the battery; that is to say, plate 2 received a *negative charge.* This negative charge tended to repel electrons from plate 1. At the same time the positive post of the battery drew away some of the electrons from plate 1 to satisfy its deficiency. Thus, a deficiency was created on plate 1 which means that a *positive charge* was placed there. The dielectric prevented the flow of electrons through the condenser from plate 2 to plate 1. We call this process, *charging* a condenser.

When you removed the battery and wires, as in Figure 47-B, the charges remained on the plates of the condenser because there was no path over which the electrons could flow from the negative to the positive plate. Then you attached a wire to plate 2 of the condenser as in Figure 47-C. So great was the tendency of the electrons piled up on that plate to get over to plate 1 (where there was a deficiency of electrons), that they could not wait for the circuit to be closed, but actually jumped across the small gap just before you touched the end of the wire to plate 1. That was the spark you saw. This process is called *discharging* a condenser.

68. The Discharge Is Oscillatory

But in their surge to get to plate 1, a good many more electrons rushed across than were necessary to make up for the deficiency. As a result, plate 1 had an excess of electrons and plate 2 a deficiency of them. The charges were thus reversed. The electrons thereupon surged from plate 1 to plate 2. Again too many rushed across and again the charges were reversed. These oscillations continued to become gradually weaker and finally stopped.

You may understand this better by comparing the motion of the electrons to the behavior of a pendulum. First consider a pendulum at rest. The weight points straight down. Now raise the weight to one side. You have created a stress in this case due to the force of gravity which tends to bring the weight to its original position. Now release the weight. It rushes back to its original position but overshoots the mark and swings on to the other side. The stress thereupon pulls it down again. It rushes back toward the lowest point but again overshoots its mark. It makes many such swings, each one of less amplitude, before it finally comes to rest.

The electrons in the condenser, when discharging across a gap or conductor, surge back and forth many times before they come to rest. All this happens in a very small part of a second. We call this swinging of electrons back and forth an *oscillatory discharge*. The capacitance of the condenser is a factor that determines the rate of oscillations.

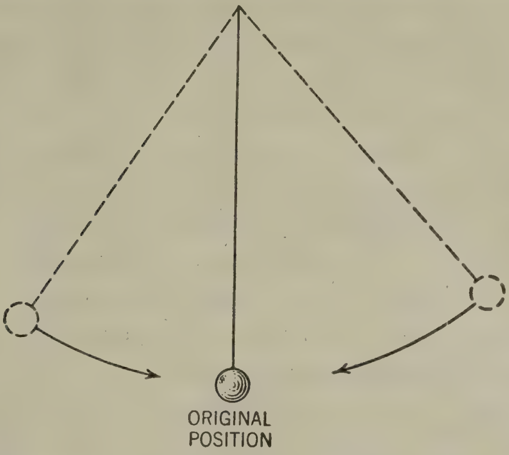

Figure 48. Diagram of pendulum illustrating electrons rushing from one plate of the condenser to the other during discharge.

SELF-INDUCTION

Our study of induction up to this point has been limited to showing how an electrical current, flowing in one coil, sets up a magnetic field that cuts across the turns of a second coil and causes a current to flow in the second coil. Now let us see what happens in the original coil.

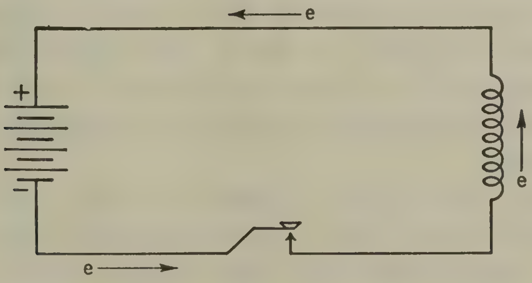

Figure 49. Hookup of coil, key, and battery to illustrate self-induction.

69. A Back Electromotive Force

Suppose you were to hook up a coil (such as your original tuner coil of 90 turns), a battery, and a key as shown in Figure 49. At the instant the key is closed, electrons start flowing from the negative post of the battery through the circuit in a counterclockwise direction, as shown by the arrows. The current flow causes a magnetic field to be built up around the coil. This magnetic field, at the instant it is formed, cuts across the turns of the coil, and sets up an electrical pressure (E.M.F.) in the coil which will start a second stream of electrons to flowing in the coil. This second stream of electrons is only momentary and always is in a direction which *opposes* the original flow of electrons sent out by the battery. The effect, however, is to slow down the speed with which the battery can send electrons through the coil.

After the key has been closed, a steady direct current will flow through the coil. The magnetic field is now stationary. The backward flowing second stream of electrons lasted only an instant, when the magnetic field was first formed. Now the original flow of electrons from the battery will pass through unhampered.

70. Self-induction

As the key is opened the magnetic field collapses. Again a changing magnetic field will cut across the turns of the coil and again it will set a second momentary stream of electrons flowing through the coil. This time the second electron stream will be in the original direction of electron flow, that is, counterclockwise. This momentary pressure now acts to oppose the stopping of the electron stream from the battery and thus it tends to keep the electrons flowing through the coil for a short interval of time after the key is opened.

In summary, the motion of electrons set up in the coil by a change in the magnetic field, at the moment the key is closed or opened, will always oppose the action of the battery. The phenomenon described above is known as *self-induction.* The self-induction of a coil is included in the idea of inductance which we are gradually trying to form. Both the size and the number of turns in a coil (that is, its "electrical size") affect its properties of self-induction.

THE TUNING CIRCUIT

71. Joining the Condenser and Coil

Now connect your condenser to the coil. This is the tuning circuit. Let us study the diagram of this circuit in Figure 50.

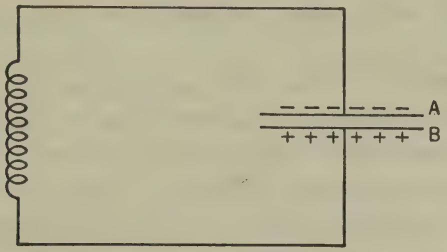

Figure 50. Tuning circuit, showing charged condenser.

Assume that a negative charge has been placed upon plate A of the condenser and a positive charge upon plate B. Now the condenser starts to discharge through the coil. The electrons surge back and forth (*oscillate*) from plate A, through the coil, onto plate B and back again, many times a second. The speed with which these electrons rush from one plate to the other (or oscillate in the tuning circuit) depends upon the electrical size of the condenser.

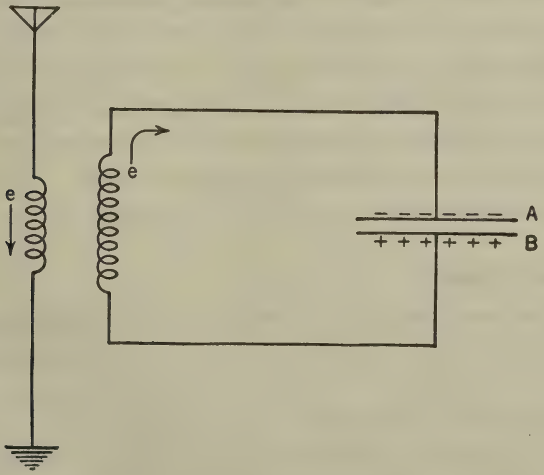

Figure 51. Diagram showing how the condenser got its charge.

But as this alternating current flows through the coil, the self-induction in that coil slows down this flow of electrons. So you see that it is really the electrical sizes of the condenser and coil that determine the rate at which the electrons oscillate in the tuning circuit. Another way of saying this is that the electrical sizes of the condenser and coil determine the *natural frequency* of the tuning circuit.

The question now arises, where does the condenser get its charge?

Examine Figure 51. You will notice that when electrons are flowing *down* the primary of the antenna coupler, they induce a voltage in the secondary which causes electrons to flow in the tuning circuit in a clockwise direction. This flow causes electrons to pile up on condenser plate A and a deficiency of electrons results on plate B. Then, for an instant before reversing their direction, the electrons will cease moving in the primary of the antenna coupler. Nevertheless, at this instant self-induction in the secondary of the coupler continues to pile up electrons on condenser plate A.

72. Reversing the Current

When the electron flow in the primary reverses itself, electrons begin to be piled up on plate B of the condenser. So you see that the flow of electrons in the primary of the antenna coupler sets a stream of electrons oscillating in the tuning circuit. The frequency of this oscillation depends upon the frequency with which the electron flow in the primary reverses itself. This frequency in turn depends upon the frequency of the radio wave.

73. Resonance Again

But we must not forget the other stream of electrons set flowing in the tuning circuit by the discharging of the condenser (see paragraph 71). The frequency of this second oscillation depends, as you have seen, upon the electrical values of the coil and condenser. Now if these two sets of oscillations are in step all is well and they will work together. But should they be out of step, they will interfere with each other and quickly destroy all flow of electrons. If they are in step, we say that they are in *resonance*. We therefore select the proper values of inductance and capacity to place our tuning circuit in resonance with the radio station we desire. Then oscillations caused by that station's wave are built up in our tuning circuit. Signals from stations of different frequencies cause oscillations that are out of step and they die away.

In practice, we keep the electrical size of the inductance constant and vary the capacity of the condenser to place our tuning circuit in resonance with the radio station we wish to receive.

SUMMARY

Read the following statements by supplying the correct terms in the blank spaces. *Do not write in the book!*

1. When a magnetic field is caused to cut through a conductor, a (1) is induced in the (2). The same effect is produced whenever a (3) and a magnetic (4) are changed relative to each other. The current induced is in one direction when the conductor passes *into* the magnetic field and in the (opposite) (same) (5) direction when the conductor passes *out* of the field.

2. When a dry cell is connected to a condenser, the plates connected to the (6) pole acquire excess electrons and the other plates have a (7) of electrons. A *spark* is caused when (8). The discharge of a condenser is said to be oscillatory because (9).

3. The magnetic field formed when a current begins to flow in a conductor sets up a momentary flow of (10) in the (same) (opposite) (11) direction to the current causing the magnetic (12). This effect is known as (13) (14).

4. The oscillations set up by the radio wave in the (15) must be in resonance with (16) in order that a given radio station may be received. The process of adjusting the set to this resonance is known as (17).

GLOSSARY

Condenser: Two metal plates separated by a dielectric.

Mutual Induction: The method by which electrical energy from one circuit is transferred to another by means of a moving magnetic field, no direct connection.

Oscillation: The periodic movement of electrons back and forth through a circuit.

Self-induction: The property of a coil, corresponding to mechanical inertia, whereby it tends to keep out a current coming in and, once in, to prevent it from discontinuing; in short, to oppose any current change through it.

QUESTIONS AND PROBLEMS

1. What is the relationship between frequency of oscillation of electrons in the aerial-ground system and frequency of oscillation in the tuning circuit of a receiver?

2. Distinguish between an electrical conductor and an insulator. Give examples.

3. Give an electronic explanation (that is, in terms of electrons) of the charging of a condenser.

4. Give an electronic explanation of the discharge of a condenser.

5. Describe the chain of the events occurring when a voltage (electromotive force) is applied across a coil.

6. Describe the chain of events occurring when the voltage applied across a coil is removed.

7. In what way does the coil of a tuning circuit serve to control the rate of discharge of the condenser.

8. Give an electronic-magnetic field picture of a tuning circuit showing how the coil and condenser control the rate of oscillation of current in the tuning circuit.

9. "The receiver is in resonance with the radio wave." Electronically, what is meant by this statement?

10. Practically, how do we place our receiver in resonance with any broadcasting station? How else might we have done it?

CHAPTER 13

Electron Flow in the Crystal Detector and Phones

Problem 1: *What are parallel circuits?*
Problem 2: *How are the detector and phones connected to the tuning circuit?*

Up to now you have seen a stream of electrons merrily oscillating through the tuning circuit many times each second. Now for the next step. Let us see what happens in the detector and the phones.

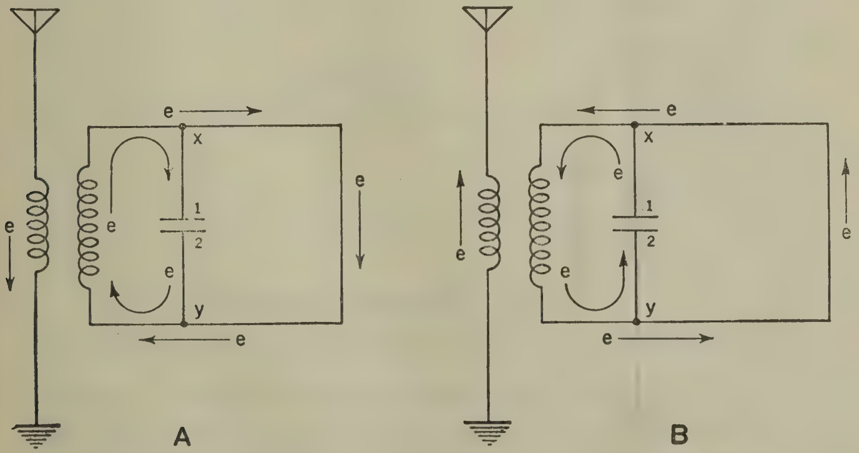

Figure 52. Parallel circuits.
A—Flow of electrons during a half cycle.
B—Flow of electrons during the next half cycle.

74. Parallel Circuits

Across the condenser of the tuning circuit, connect a loop of wire as in Figure 52.

When a stream of electrons flows down the primary of the antenna coupler (Figure 52-A), another stream is set flowing in a clockwise direction through the tuning circuit and electrons are being piled up on plate 1 of the condenser. At point *X*, however, the path divides and some of the electrons are being pushed around through the loop of wire and back to the main stream at point *Y*. We say that these two paths or circuits are parallel to each other. A parallel circuit is also called a *shunt*. In parallel circuits, the electrons have two or more paths and flow at the same time through all of these paths.

When the flow of current reverses itself (Figure 52-B), the stream of electrons divides at point *Y*, some flowing onto plate 2 of the condenser while others flow through the loop of wire and rejoin the other electrons at point *X*.

In other words, electrons flow through the loop of wire (the parallel circuit) in the same direction as the flow of electrons in the tuning circuit and in step with it.

75. The Crystal Detector in a Parallel Circuit

Now substitute the crystal detector and the phones for the loop of wire.

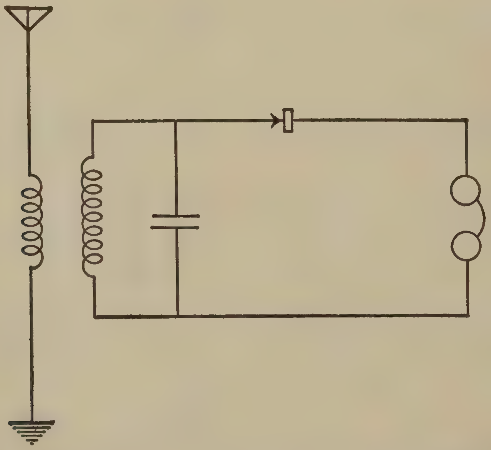

Figure 53. Diagram showing crystal detector and phones substituted for the loop of wire.

Electrons then tend to flow through the detector and phones in step with the flow of electrons in the tuning circuit.

But hold on! You will remember that the crystal detector acts like an electrical gate, permitting electrons to flow through it only in one direction. Therefore, although the electrons flow back and forth in the tuning circuit, they can only flow through the detector and phones in one direction. This means that because of the crystal detector, the current that flows through the phones is not an alternating current, but a pulsating direct current. (See Chapter 9, Figure 32.)

76. The Phones

The pulses reaching the phones are a series of electron streams, each of very short duration, perhaps one one-millionth of a second or less. Also, the current is direct current, that is, the electrons always move in one direction. You already know that each such electron stream is of too short duration to move the diaphragm of the phones. But when a series or train of such electron streams push together they can cause the diaphragm to fluctuate and you can hear a sound. We will investigate how they do it.

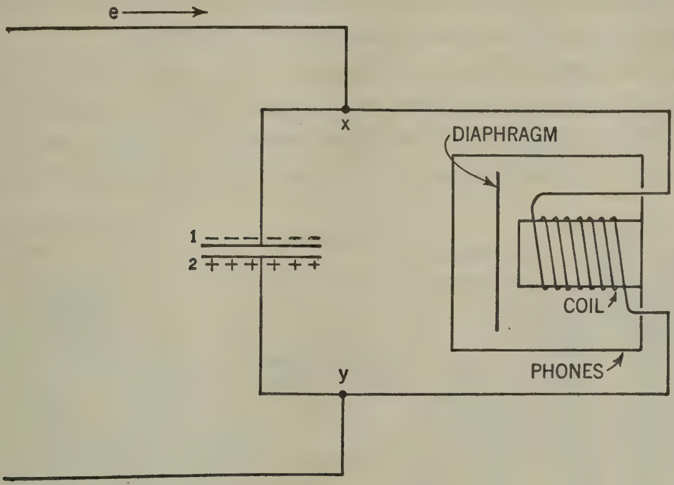

Figure 54. Diagram showing how electrons flow through the phones.

77. Using a Fixed Condenser across the Phones

Across the phones (parallel to the phones) connect a fixed condenser. The stream of electrons from the tuning circuit has already passed the detector and now approaches the phones, as indicated by the arrow in Figure 54.

At point *X* this stream divides. One part attempts to pass through the coil of the phones and the other part piles up electrons on plate 1 of the condenser. The part attempting to pass through the phones encounters considerable difficulty because the many turns of thin wire in the coil in the phones present a good deal of resistance to the flow. Because of the very short duration of electron flow, only a few electrons find their way through. Most of the electrons, then, pile up on plate 1 of the condenser.

When the next stream comes along the same thing happens. More and more electrons continue to pile up on plate 1 of the condenser. The greater the negative charge on plate 1 the greater the positive charge that appears on plate 2 and the greater the tendency of the electrons on plate 1 to make up the deficiency on plate 2.

Since the only way the electrons on plate 1 can get to plate 2 is through the coil of the phones, they must wait until enough electrons have been piled up on plate 1 to overcome the resistance offered by the coil. When that pile-up occurs, they all rush over in one grand surge and the diaphragm is strongly attracted. It is these surges of electrons through the coil of the phones that cause the diaphragm to fluctuate and produce a sound.

You will recall that in Chapter 9 we said that the current flowing through the phones can be pictured by drawing a line through the peaks of all the direct-current pulses passing out of the detector; we called this line the envelope. Well, strictly speaking, this is not the true picture. Actually, the effect of the condenser is to level off the peaks of these pulses and fill in the hollows. The curve now presents a continuous line whose fluctuations resemble those of the envelope. Since it is these fluctua-

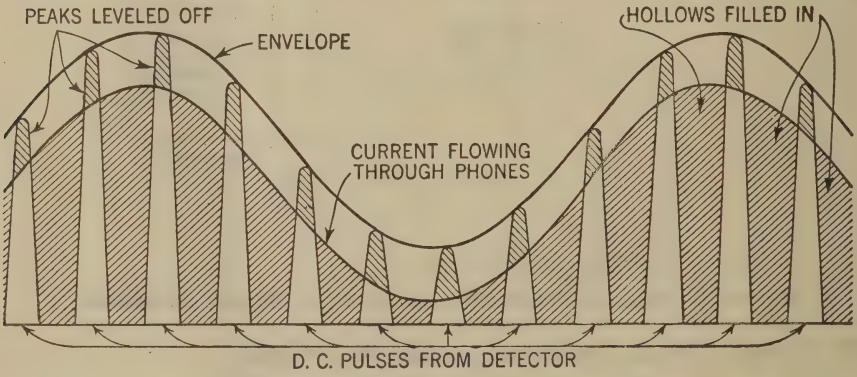

Figure 55. Graph showing how the condenser levels off the peaks and fills in the hollows between the pulses of direct current coming from the detector. Note that the resulting curve resembles the envelope quite closely.

tions that produce the to and fro motion of the diaphragm, the sound coming from the phones is very nearly like the sound first created at the broadcasting station.

78. Coils as Condensers

Let us now go back to that fixed condenser across the phones. You will have noticed that in our circuit diagrams of the crystal receiver we have omitted it. Nevertheless, it was always present. Here is why.

A condenser, you know, consists of two metallic plates separated by an insulator. In the coil of the phones we have many turns of copper wire wound next to each other and separated by an insulator. So you see that if we consider two turns of wire next to each other and separated by an insulator, we really have a very small condenser. Since there are hundreds of such small condensers in the coil, the total effect is the same as though a large condenser were connected across the phones. Thus a coil serves both as an electromagnet and a condenser at the same time.

In practice, an external condenser having a capacity of .006 μfd. is sometimes placed across the phones even though it is not absolutely necessary.

SUMMARY

1. Any electrical device is connected **in parallel** in a circuit when it is one of two or more paths through which some of the current can flow. Devices are said to be **in series** when all of the current must pass through all of the devices one after another.

2. A condenser is usually connected in parallel with the phones.

3. In the graph of the current flow, the **envelope** is a fluctuating heavy line showing the peaks of the pulses that produce the sounds in the phones.

GLOSSARY

Parallel Circuit: An electrical circuit in which electrons have two or more paths to follow in going from the negative to the positive pole.

Shunt: One of the paths in a parallel circuit.

Series Circuit: A circuit in which electrons have but one path.

QUESTIONS AND PROBLEMS

1. Draw a dry cell connected to two parallel circuits.

2. Show how electrons behave in a crystal receiver in going through the crystal and phones, the latter being in parallel with the tuning circuit.

3. What is the nature of the current through the phones of a crystal receiver? Indicate it graphically.

4. Describe the action of the fixed condenser across the phones in the crystal receiver, from an electronic point of view. Why may it be omitted?

5. What is the rated value of the condenser placed across the phones?

CHAPTER 14

The Vacuum-tube Detector—The Diode

Problem 1: *What is meant by the "Edison effect"?*
Problem 2: *What are the principles of a Fleming valve?*
Problem 3: *What is the "diode" detector?*

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79. Faults of the Crystal Detector

Having mastered the theory of the crystal receiver, we are now ready to go ahead. If you have constructed the receiver described here and "listened in" on it, you must be aware that the crystal detector has shortcomings. First of all, it is difficult to manipulate. Not every spot will work. You must move the cat-whisker about for some time before you touch a spot which enables you to hear radio signals in your phones.

Even after you have found the proper spot, a slight jar may dislodge the fine wire and the hunt starts over again. Perhaps dirt, grease, or oxidation from the air may spoil the sensitive spot and you have to start once again.

80. The Edison Effect

Oddly enough, the first hint as how to improve the detector came in 1883, long before the crystal detector was first used in a radio receiver. In that year Thomas A. Edison was experimenting with filaments for his new invention, the electric light bulb. He placed a filament in a glass bulb and then exhausted the air, creating a vacuum. By means of an electric current, he heated the filament until it glowed brightly and produced light.

He soon observed an undesirable feature about his bulbs. After a short time, a black substance was deposited on the inside of the glass, interfering with the light given out. In an attempt to stop this deposit on the glass, he inserted a metal plate. Now this plate did not help much, but one day he connected a delicate electric meter between the plate and one end of the filament. To his amazement, the meter showed that a small electric current was flowing through the circuit.

He did not know why this current should flow and he merely jotted down this strange fact in his notebook and forgot about it.

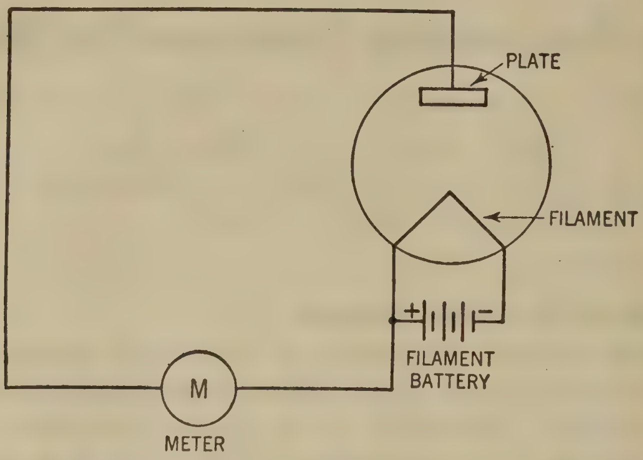


Figure 56. Diagram showing Edison's experiment.

Today, we know why this current flows. When a filament is heated to incandescence (when it becomes hot enough to give off light), it shoots off streams of electrons. This behavior is known as the "Edison Effect" or *thermionic effect* of a filament heated to incandescence.

These electrons given off by the hot filament collect on the cool plate and, if a path is furnished them, they will flow along this path toward the filament. The meter in that path shows that electrons are flowing.

81. The Fleming "Valve"

As we stated, this discovery of Edison's was made in 1883. At that time, the electron theory was not known. But in 1904, J. Ambrose Fleming, an Englishman, who understood the flow of the current in terms of electrons, decided to experiment a bit. To depend upon the electrons piling up on the cool plate, thought Fleming, is too slow. Suppose we were to create an actual deficiency of electrons on the plate by placing a positive charge on it, wouldn't that attract still more electrons from the filament? Fleming connected a battery in the circuit from the plate to the filament, in such a way that the positive post of the battery was connected to the plate (see Figure 57). He also connected another battery to the filament to heat it to incandescence. Note that this filament battery is not in the plate circuit.

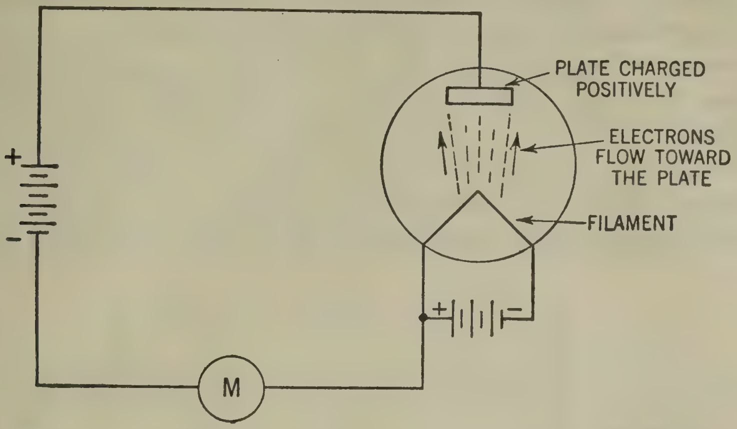


Figure 57. Fleming's experiment with a positive charge on the plate of the tube. The meter showed that an electric current was flowing through it.

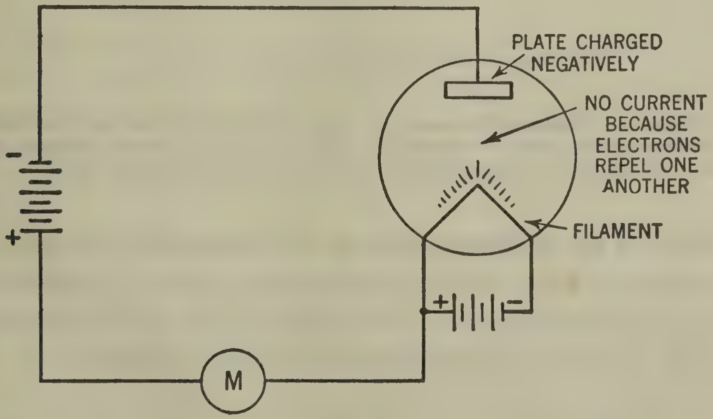


Figure 58. Fleming's experiment with a negative charge on the plate of the tube. The meter showed that no electric current was flowing through it.

By this arrangement some of the electrons of the plate were pulled away to satisfy the deficiency at the positive post of the battery. This removal resulted in a deficiency of electrons on the plate, that is, a positive charge. Fleming now connected a meter in the circuit and, as he had expected, a much greater stream of electrons flowed through than before the battery was attached. He also discovered that the more powerful the battery, the greater the positive charge on the plate, the more electrons were attracted, and the greater the current flow through the meter.

Now Fleming reversed the connection to the battery and observed that the meter showed no current. The explanation is that this time the battery piled electrons onto the plate (gave it a negative charge) and electrons repel each other. Hence the stream of electrons from the filament was repelled from the plate and therefore no current flowed through the meter (see Figure 58).

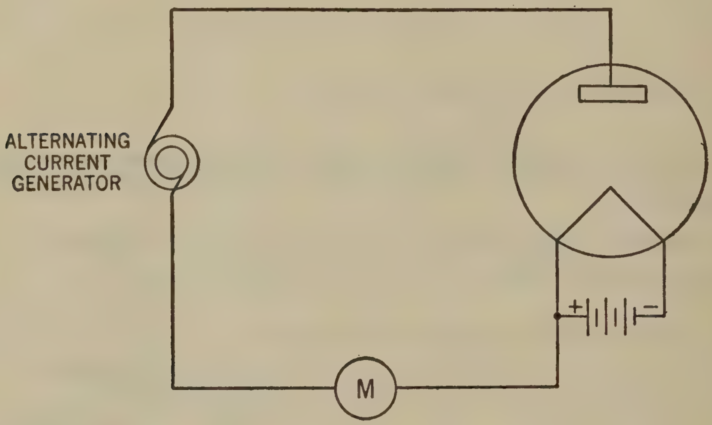
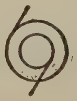


Figure 59. Fleming's experiment with an alternating-current generator connected to the plate of the tube. Electric current flowed through the meter only during the positive half of the alternating-current cycle.

82. Effects of the Fleming Valve on an Alternating Current

By means of an alternating-current generator, Fleming now replaced the direct current of the battery with an alternating current. The symbol for the alternating current generator is:



When the proper instruments were attached and the meter reading taken, Fleming now observed that the current flowing through the meter was direct, not alternating. The explanation (see Figure 59) is as follows: During the positive half of the alternating-current cycle the plate received a positive charge.

This charge caused electrons from the heated filament to be attracted to the plate and a current flowed in the circuit as registered on the meter. During the negative half of the alternating-current cycle the plate received a negative charge. This charge repelled the electrons from the filament and the meter showed that no current was flowing. The effect of this action upon the graph of the wave form is shown in Figure 60. Only a pulsating direct current is passing through the meter.

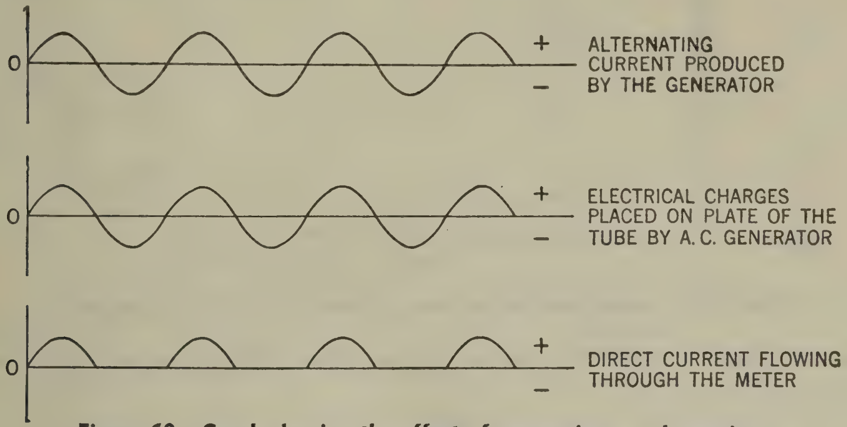


Figure 60. Graph showing the effect of connecting an alternating current generator to the plate of Fleming's tube.

Here, then, is an electrical "gate" or "*valve*" that will permit current to flow only in one direction. As a matter of fact, the early radio tubes were all called valves and are still called by that name in England.

Doesn't this sound familiar? Of course! The crystal detector acted in just that way.

83. The Fleming Valve as a Detector

Fleming went one step further. For the alternating-current generator he substituted a radio tuning circuit. Since alternating current flows out of the tuning circuit, it may be considered a sort of alternating-current generator. For the meter Fleming substituted a pair of phones and now he had the same hookup as our old receiving set with a new kind of detector to replace the crystal. (See Figure 61.)

84. Why the Fleming Valve Is Called a Diode

This type of detector is known as a *Fleming valve.* Because it has two electrodes, the filament and plate, it is also known as a *diode* (*di*-means two; -*ode* means pole). It is easier to to operate than a crystal because there is no need to hunt for a sensitive spot. Further, you can not disturb it by jarring; and no dirt, grease, or air can get inside the sealed glass tube. The symbol for the diode is:

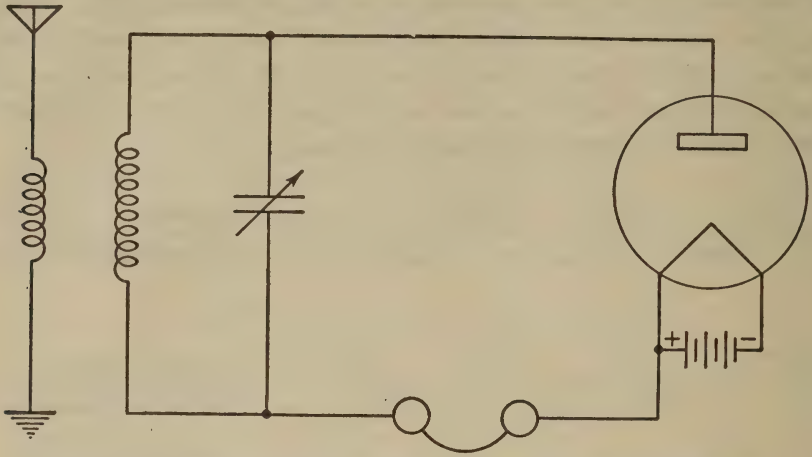
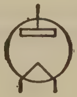


Figure 61. Radio receiving set using a Fleming valve as a detector.



SUMMARY

1. Thomas Edison, in 1883, discovered that in a vacuum tube an electric current passed from a hot filament through the vacuum to a plate sealed in the tube at some distance from the filament.

2. J. Ambrose Fleming in 1904 discovered that the current was increased in an Edison tube when the plate was made positive and ceased when the plate was made negative.

3. The "diode" or Fleming valve depends upon the principle that alternating currents passed through the tube are changed to direct currents because only during the positive half of an alternating-current cycle are the electrons attracted from the filament to the plate.

GLOSSARY

Catwhisker: The thin wire with which we hunt for a sensitive spot on the crystal.

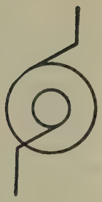
Diode: A two-electrode tube containing a plate and filament.

Fleming Valve: A tube ("valve") used as a detector.

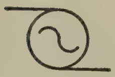
Thermionic Effect: The throwing off of electrons by a body when it is heated to incandescence.

"Valve": A tube with a filament and plate which will allow current through it only in one direction.

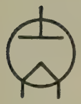
SYMBOLS



or



A.C. generator.



Diode.

QUESTIONS AND PROBLEMS

1. Give the defects of a crystal as a detector.
2. Describe Edison's early experiment on vacuum tubes.
3. Why did a current flow from the plate to the filament in Edison's electric light bulb when the two were connected externally?
4. How did Fleming make use of the Edison effect to improve the vacuum tube?
5. What occurs in the tube containing the filament and plate when the plate is made negative?
6. Draw a graph showing the resulting effect when an alternating-current sine voltage is impressed on the plate of Fleming's valve.
7. In what way are the crystal detector and the Fleming valve alike?
8. To what electrical machine does a tuning circuit correspond?
9. What energizes the tuning circuit to make it act as the machine in question 8?
10. What is the advantage of the diode over the crystal as a detector?
11. Draw a one-tube receiver using the Fleming valve as a detector.

CHAPTER 15

The Vacuum-tube Detector—The Triode

Problem 1: *What did De Forest contribute to radio?*
Problem 2: *By what principles does the "grid" function?*
Problem 3: *How is the grid maintained with the proper negative charge?*
Problem 4: *What is the principle of volume control?*

Soon after Fleming's diode tube appeared, in 1907, an American inventor, Lee De Forest, undertook to carry further some ideas suggested by one of Fleming's experiments. De Forest knew that when Fleming placed a positive charge on the plate of his tube by means of a battery connected between the plate and filament (Figure 57), a much greater electric current flowed through the meter than when there was no such charge. Further, the greater the positive charge on the plate, the greater the flow through the meter. (Actually, this did not go on forever. After the positive charge reached a certain value, placing a greater positive charge on the plate had no further effect.)

85. "A" and "B" Batteries

The circuit traveled by the electrons—starting from the filament of the tube, going across the vacuum in a stream to the plate and back again to the filament by way of the path provided by the meter, battery, and wire—is known as the *plate circuit.* The battery used to place a positive charge on the plate is known as the *plate battery* or *B battery.* The battery used to heat the filament is known as the *filament battery* or *A battery.* (See Figure 62.)

86. Experiments of Lee De Forest

Now, thought De Forest, if we could only use the advantages of the B battery and substitute our phones for the meter, we would get a much louder signal in our phones. For the greater the current flowing through the phones, the greater is the magnetic pull of the coil. Greater magnetic pull means that the diaphragm is bent more; the air is set moving more violently, and a louder signal results.

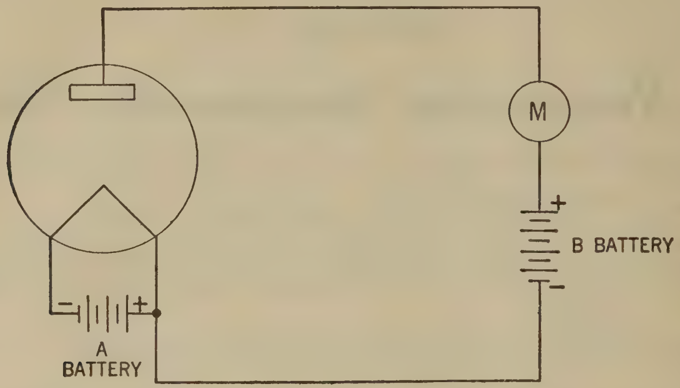


Figure 62. Diode using a B battery to place a positive charge on the plate of the tube. Current flows through the meter.

At this point, however, a serious difficulty arose. The large current through the phones must be a direct current that fluctuates in step with the fluctuations of the incoming signal. De Forest quickly discovered that the small charges placed on the plate of the Fleming valve by the alternating current from the tuning cir-

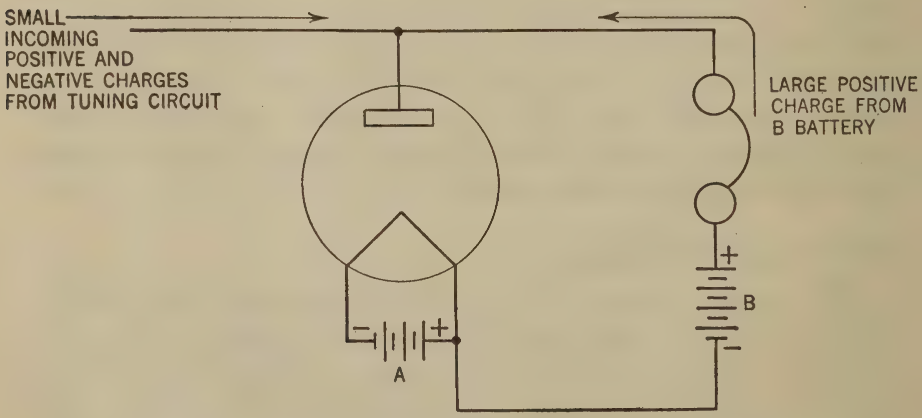

SMALL INCOMING POSITIVE AND NEGATIVE CHARGES FROM TUNING CIRCUIT
LARGE POSITIVE CHARGE FROM B BATTERY
+
B
−
+
A

Figure 63. Diagram showing how the weak positive and negative charges placed on the plate of the diode are overwhelmed by the large positive charge placed on the same plate by the B battery.

cuit were undetectable in the presence of the relatively enormous positive charge placed on the plate by the B battery. Try as he would, De Forest could not utilize the advantages of a B battery in the diode tube. (See Figure 63.)

87. Discovery of the Grid

It was then that De Forest had a stroke of genius. Since the flow of current in the plate circuit starts with the stream of electrons shot out by the heated filament, he began to experiment with that electron stream.

Suppose, thought he, we were to place another electrode in the tube between the filament and plate. Being closer to the filament than the plate, this electrode would have a greater effect on the stream of electrons than would the plate. Thus a small positive charge on this new electrode would pull over electrons just as would a large positive charge on the plate. Also, a small negative charge on this new electrode would repel the stream of electrons and none would reach the plate. When no electrons reach the plate, no current flows in the plate circuit. Here, then, thought De Forest, is a method for controlling the flow of current in the plate circuit by means of small charges on the new electrode.

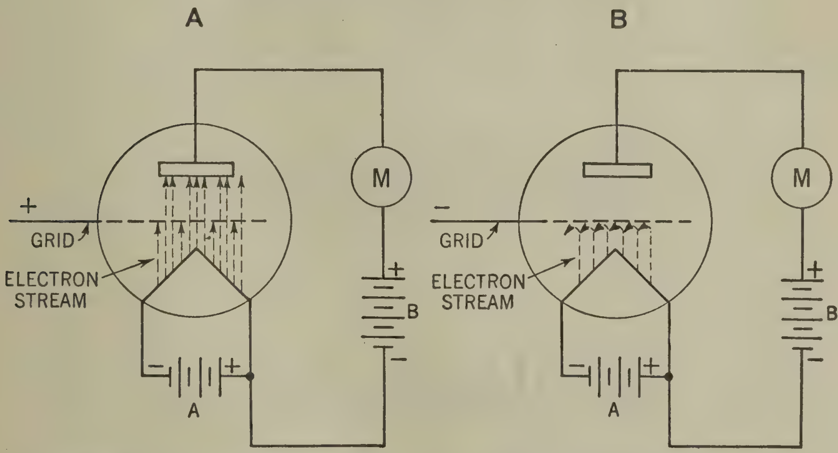


Figure 64. A—Diagram showing how a positive charge on the grid of De Forest's tube helps pull electrons from the heated filament to the plate. The meter shows that an electric current is flowing through it.
B—Diagram showing the effect of a negative charge on the grid. Electrons from the heated filament are repelled and none reach the plate. The meter shows that no current is flowing through it.

But hold on! Further reasoning and experimenting convinced De Forest that when this new electrode was given a positive charge it pulled over electrons, as expected—but these electrons went to this new electrode and none found their way to the plate. After more experiments, De Forest eventually met this difficulty by making the new electrode in the form of a mesh of very fine wire, a *grid.* Since most of the grid consisted of open space, most of the electrons pulled over by a positive charge on the grid now shot through these open spaces and continued right on to the plate. The grid was the solution to his problem. (See Figure 64.)

88. How the Grid Works

By study of the diagram in Figure 65, we can obtain an idea of how charges on the grid affect the flow of current in the plate

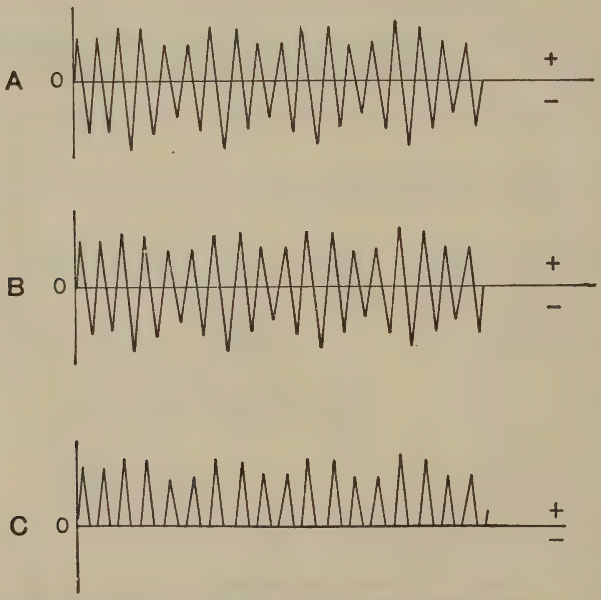


Figure 65. Graphs showing flow of electric current in various parts of the triode circuit.
A—Alternating current flowing from the tuning circuit.
B—Positive and negative charges placed on the grid of De Forest's tube by this alternating current from the tuner.
C—Fluctuating direct current flowing through the meter.

circuit. If the grid has a small negative charge it repels some of the electrons shooting off from the filament and only a few of these electrons pass through the open spaces of the grid to the positive plate. A small current flows through the plate circuit and thus through the phones.

As the negative charge on the grid gets larger and larger, more and more electrons are repelled until none get through and therefore no current flows in the plate circuit.

As the grid gets a positive charge, it accelerates or speeds up the flow of electrons from the heated filament to the plate. The pull of the grid is now added to the pull of the plate. Most of the electron stream goes through the openwork of the grid to the plate. The more positive the grid gets, the greater the pull it exerts on the electrons; consequently, more electrons reach the plate and the plate current is greater.

89. How the Triode Works

Since charges on the grid control the flow of electrons from the filament, we are able to control the flow of the large plate currents by means of a small charge on the grid. And this is just what De Forest set out to do. (See Figure 66.)

He connected the small alternating-current output from the tuning circuit to the grid and studied the effects of various combinations upon the current in the plate circuit. When the positive half of the cycle of the alternating current from the tuner placed a positive charge on the grid, a large current flowed in the plate circuit. When the negative half of the cycle of the alternating current from the tuner placed a negative charge on the grid, no

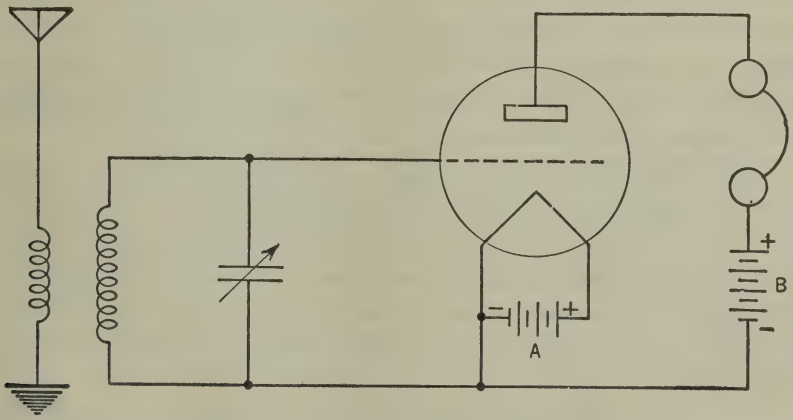
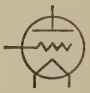


Figure 66. Diagram showing how alternating current from the tuning circuit places positive and negative charges on the grid of De Forest's tube.

current flowed in the plate circuit. These effects are shown by the graphs in Figure 65.

Now the remodeled tube, with its three parts—filament, grid, and plate—acts like an electrical gate or valve just as did the crystal detector and the diode tube. But this tube has the additional advantage that now the current that flows through the phones is not the small electrical current captured by the aerial but the very large current supplied by the B battery. Hence our signals will be much louder.

Because this new tube has three elements—the filament, the grid, and the plate—it is known as a *triode*. The symbol for the triode is:



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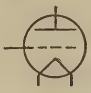


90. Wiring Diagrams Show Paths of Electrons

Look at the diagram in Figure 66. You will notice a number of paths or circuits through which electrons may flow. There is the *aerial-ground system* or *circuit*. Then there is the *tuning circuit,* consisting of the secondary of the antenna coupler and the variable condenser. Then there is the *filament circuit* consisting of the A battery and the filament. There is the *plate circuit* consisting of the filament, the stream of electrons from the filament to the plate, the plate, the phones, the B battery and the conductor leading back to the filament.

Finally there is the *grid circuit.* This path consists of the filament, the stream of electrons from the filament to the grid, the grid, the tuning circuit, and the conductor leading back to the filament. Just as current will flow through the plate circuit only when there is a positive charge on the plate, current will flow through the grid circuit only when there is a positive charge on the grid.

91. Electrons Pass through a Weak Negative Charge

You may have noticed a difficulty by now. In the diode, the bottom loop of the alternating-current cycle was completely cut off because the moment our plate went negative, all plate current ceased. The current flowing through the phones then fluctuated in step with the variations of the envelope and the signal was faithfully reproduced. (See Figure 67.)

But in the triode, connected as in Figure 66, the stream of electrons from the heated filament to the plate would continue to flow, even though the grid were slightly negative. In fact, this flow of electrons would continue until the grid assumed a fairly high negative charge, because of the relatively high positive charge on the plate. Thus plate current, and current through our phones, would flow during part of each negative cycle. In Figure 68-C we see that the graph of the current flowing through the phones does not correspond to the shape of the envelope. The practical effect is that our signal in the phones is distorted.

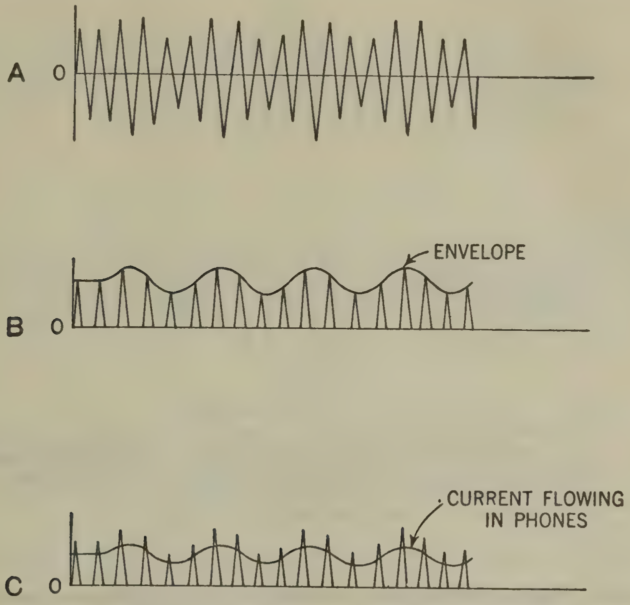


Figure 67. Graphs showing flow of electric current in various parts of the diode circuit.
A—Alternating current flowing from the tuning circuit.
B—Pulsating direct current flowing in the plate circuit.
C—Fluctuating direct current flowing through the phones. Notice how closely the fluctuations here follow the fluctuations of the envelope in part B of this figure.

92. The Use of a C Battery

Here is how this difficulty was overcome. A small negative charge was placed on the grid by means of a battery. This charge was made too small to cut off all the electrons streaming from the heated filament to the plate. Now the alternating current from the tuner was fed into the grid. (See Figure 70.)

When the positive half cycle of the current from the tuner flowed into the grid, it reduced the negative charge placed there originally. This reduction meant that fewer electrons from the filament were repelled and more of them reached the plate. This greater flow of electrons in turn meant a larger plate current.

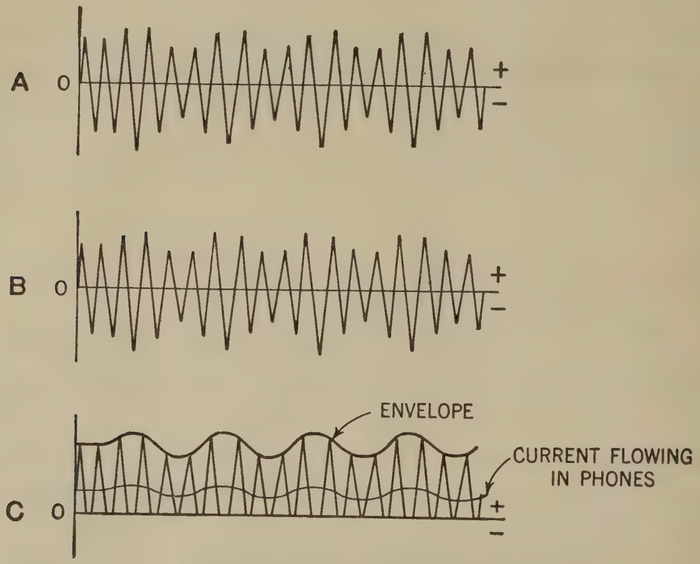


Figure 68. Graphs showing flow of electric current in various parts of the triode circuit.
A—Alternating current flowing from the tuning circuit.
B—Positive and negative charges placed on the grid of the triode by that alternating current from the tuner.
C—Fluctuating direct current flowing in the plate circuit. Notice that the current flowing in the phones is very nearly a steady direct current in no way resembling the fluctuations of the envelope. This current will cause no sound or else a distortion of the signal will be heard in the phones.

When the negative half cycle of the current from the tuner flowed into the grid, this current, by itself, could not place a negative charge on the grid great enough to cut off completely the flow of electrons to the plate. But if it were added to the negative charge we originally placed on the grid, then it would be able to stop the flow of electrons and thus to stop the flow of the plate current.

Now, you can see, no current will flow in the plate circuit during the negative half cycle of the current from the tuner. Just as in the case of the diode, the fluctuations in the current flowing through our phones correspond to the shape of the envelope and, once again, our signal is faithfully reproduced. (See Figure 69.)

We place this constant negative charge on the grid by connecting a small battery in the grid circuit in such a way that the negative post of the battery is hooked up to the grid.

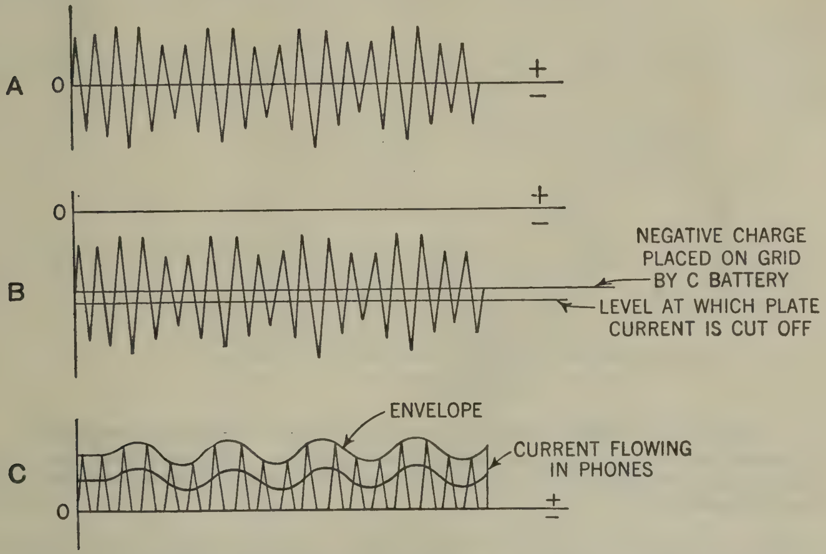


Fig. 69. Graphs showing effect of placing a steady negative charge or bias on the grid of the triode.
A—Alternating current flowing from the tuning circuit.
B—A steady negative charge or bias makes the grid negative. The positive half-cycle of the current from the tuner makes the charge on the grid less negative. The negative half-cycle of the current from the tuner makes the charge on the grid more negative to the point where the flow of current in the plate circuit is cut off.
C—Fluctuating direct current flowing in the plate circuit. Notice that now the current flowing in the phones resembles the envelope.

This battery is called a *C battery,* or *grid-bias battery.* It must be of such a size that, by itself, it cannot cut off the flow of electrons from the heated filament to the plate, but when added to the negative charge of the current flowing from the tuning circuit, it can do so. The size of this battery differs for different types of tubes. Each tube manufacturer supplies data to show how large this battery should be.

93. The C Battery May Be Replaced by a Condenser

While the C battery is effective in placing a negative charge on the grid of the triode, it wears out in time and we are faced with the nuisance of periodically replacing it. Accordingly, another method was evolved to accomplish the same result without the use of the battery—a small fixed condenser was placed in the grid circuit as shown in Figure 71.

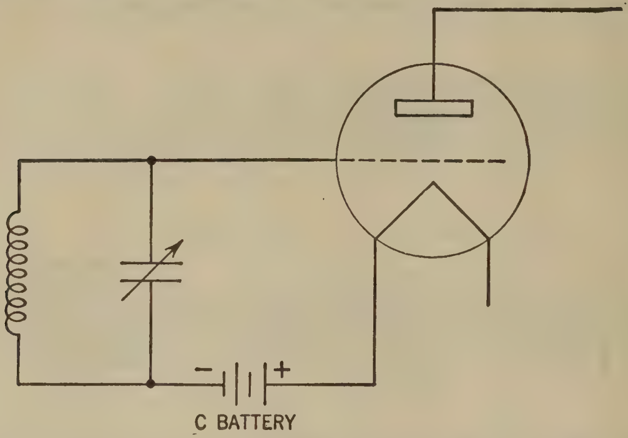


Figure 70. Diagram showing how a "C" battery is connected to place a negative charge or bias on the grid of the triode. The completed diagram would include the earphones, "A" and "B" batteries connected just as in Figure 66.

Here is how it works. When the negative half-cycle of the alternating current from the tuning circuit reaches plate 1 of the condenser, as shown in Figure 72-A, it places a negative charge on that plate. This charge drives off some of the electrons from plate 2 of the condenser. These electrons seek to get as far away as possible from the negative charge. As a result they are driven

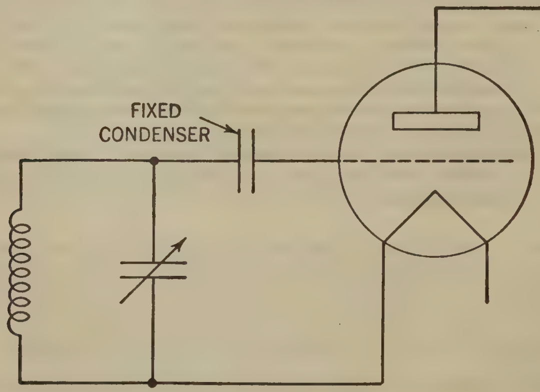


Figure 71. Diagram showing how a fixed condenser is connected to place a negative charge or bias on the grid of the triode.

onto the grid of the tube. Here they remain, for the grid is cold and therefore cannot shoot off any electrons. Thus the grid gets a negative charge. But this charge is too small to stop entirely the flow of electrons from the heated filament to the plate.

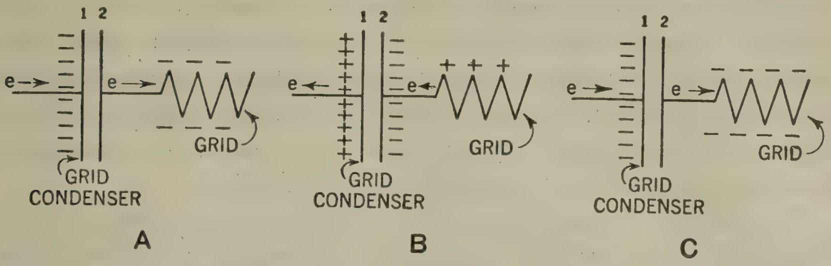


Figure 72. The action of the grid condenser.
A—A negative charge is placed on plate 1 of the condenser by current from the tuning circuit.
B—A positive charge is placed on plate 1 of the condenser by current from the tuning circuit.
C—Another negative charge is placed on plate 1 of the condenser by current from the tuning circuit.

During the positive half-cycle of the alternating current from the tuner, a positive charge is placed on plate 1 of the condenser (Figure 72-B.) The electrons on the grid now are attracted back to plate 2. This movement leaves the grid with a positive charge and most of the electrons shot out by the heated filament of the tube rush to the plate of the tube. It should be noted, however, that some of these electrons strike the positively charged wires of the grid and are pulled over to plate 2 of the condenser.

During the next (negative) half-cycle, electrons are again piled up on plate 1 of the condenser (Figure 72-C). Once again electrons stream away from plate 2 to the grid. This time, however, there are more electrons on the grid. The electrons that were collected by the grid from the stream shot out by the filament during the positive half cycle have been trapped and cannot get away. So this time the grid has a larger negative charge.

As this process goes on, a larger and larger negative charge is collected by the grid. You see, we now have the same effect as when we placed a C battery in the grid circuit.

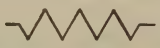
94. The Function of the Grid Leak

But this process must not be permitted to go on indefinitely. Soon there will be accumulated upon the grid enough electrons to completely stop any electrons from reaching the plate of the tube.

Since the electrons are trapped there, the action of the tube will be completely blocked and no signal can get through.

A method had to be worked out, therefore, to permit some of these electrons to flow off. A path was provided across the condenser so that when a positive charge was placed on plate 1, some of these trapped electrons could flow across to that plate. Provision had to be made so that not all of these trapped electrons could escape, for that would destroy the effectiveness of the condenser. Only enough of them should be permitted to leak off so that the action of the tube would not be blocked.

To provide this path, a *resistance* is connected across the condenser. A resistance is a substance that retards the flow of electrons through it. It is usually made of a special type of wire such as nichrome or of certain substances such as carbon. The greater the resistance the fewer the electrons that can flow through it. The symbol for a resistance is:



In Figure 73, you have the diagram of a receiving set using a triode as a detector. The tube used is a type called 01A. This tube requires an A or filament battery of 6 volts. The B or plate battery is 22½ volts. The condenser used in the grid circuit is called a *grid condenser*. This condenser usually uses mica as a dielectric and its value is .00025 μfd.

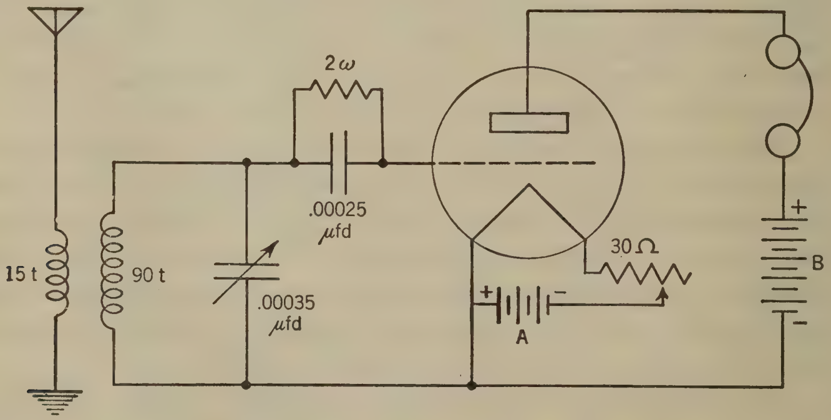
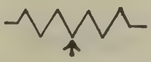


Figure 73. Diagram of the complete receiving set using the triode as a detector. The symbol 2ω over the grid leak stands for 2 megohms (2,000,000 ohms). The symbol 30Ω over the rheostat stands for 30 ohms.

Across this condenser is the resistance which furnishes the path by means of which the excess electrons *leak* off the grid. Quite naturally it is called a *grid leak.* The unit for measuring resistance is the *ohm.* The value of the grid leak is 2,000,000 ohms or 2 megohms, the prefix "meg" meaning a million.

95. Volume Control

In the filament circuit, between the A battery and one end of the filament, you will notice a device shown by the symbol:



This is the symbol for a variable resistance or a *rheostat.* This rheostat controls the amount of current that can flow from the A battery to the filament. The resistance offered by this rheostat can be made greater or less by increasing or decreasing the length of wire through which the current must pass. This variation in length is produced by a sliding contact or by a switch moving over contact points connected to various points on the wire. Since the more current flowing through the filament, the hotter it gets, this rheostat then controls the heat of the filament. The hotter the filament, the more electrons it shoots off. The rheostat therefore controls the quantity of electrons shot off by the filament.

The more electrons hitting the plate, the greater the plate current. The greater the plate current, the greater the current through the phones and the louder the volume of the signal. So you see that this rheostat finally controls the volume of the signal.

As you have probably guessed, this rheostat is called a *volume control.* Its value is about 30 ohms.

Our receiving set, now, is quite an improvement over the one shown in Figure 22. By means of an antenna coupler we have improved its *selectivity,* that is, the ability to select the radio station desired and to reject all others. The use of the triode as a detector has increased the set's *sensitivity.* Now stations which were too weak to be heard on a crystal or diode detector set are heard in the phones.

SUMMARY

1. Lee De Forest, an American, devised the **triode** tube.
2. The principle of the triode is that a third element called a **grid** is placed in the vacuum tube between the filament and plate.
3. The grid, when charged positively, permits electrons to flow

through it to the plate, but retards the flow of electrons when it is charged negatively.

4. By means of a **C battery** or by means of a **condenser** and **grid leak** the grid may be given a negative charge of the right amount.

5. This right amount of negative charge is that charge which will not prevent electrons going from the filament to the plate during the positive half of an alternating-current cycle, but will prevent them during the negative half of the alternating-current cycle.

6. The heat of the filament, and hence the volume of the signal, is controlled by a variable resistance or **rheostat.**

GLOSSARY

A Battery: The battery used to heat the tube's filament; also known as the **filament battery.**

B Battery: The battery used to place a positive charge on the plate of the tube. Also known as the **plate battery.**

C Battery: The battery used to place a fixed negative charge or bias on the grid of the tube. Also known as the **grid-bias battery.**

Circuit, filament: The path of electrons from the A battery, through the filament and back to the A battery.

Circuit, grid: The path of electrons from the filament to the grid of the tube, through connecting wires and electrical apparatus and back to the filament.

Circuit, plate: The path of electrons from the filament to the plate of the tube, through connecting wires and electrical apparatus and back to the filament.

Grid: An open-mesh metal screen, placed between the plate and the filament of the tube, that controls the stream of electrons going from the filament to the plate.

Grid bias: The fixed negative charge placed on the grid on the tube.

Grid condenser: A small fixed condenser placed in the grid circuit of the tube and used to hand on the electrical energy from the tuning circuit. This condenser also blocks the flow of electrons, accumulated on the grid, through the grid circuit.

Grid leak: A resistor placed across the grid condenser to provide a slight path or leak for the electrons accumulated on the grid of the tube.

Meg-: A prefix meaning 1,000,000.

Ohm: The unit in which we measure the resistance to the flow of electrons.

Rheostat: A variable resistor.

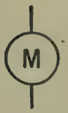
Selectivity: The ability of a tuner to select one radio station signal and reject all others.

Sensitivity: The ability of a radio receiver to respond to radio waves of very low strength.

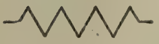
Triode: A three-electrode tube containing a filament, grid, and plate.

Volume control: A resistance device, usually a rheostat, which controls the volume of the radio signal coming out of the earphones or loudspeaker.

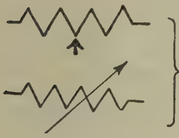
SYMBOLS



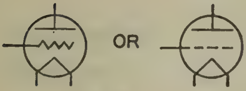
Meter.



Fixed resistor.



Variable resistor or rheostat.



Triode.

QUESTIONS AND PROBLEMS

1. Up to a certain saturation point, what is the effect of placing a higher positive voltage on the plate?
2. Why can't a B battery be used with a diode detector receiver?
3. How does the grid control the current flowing from the filament to the plate?
4. Impress an alternating voltage on the grid of a tube and make a graph of the current in the plate circuit.
5. Describe the construction of a triode.
6. Why should a triode be capable of giving louder signals in a receiver than a diode detector?
7. What function does the radio-frequency current serve in a triode when it is fed onto the grid?
8. What effect results from a positive voltage on the grid?
9. What purpose does the C battery serve? What is the C battery said to give the grid?
10. In what manner does the grid bias enable the triode to act as a detector?
11. How can we determine the magnitude of the grid bias used?
12. What disadvantage occurs when we use a C battery for a grid bias?
13. Explain the operation of a grid leak and grid condenser in making the triode act as a detector.
14. What is the function of a rheostat in the filament circuit? Explain how it carries out this function.
15. Draw a one-tube receiver using a triode as a detector and using a C battery as a grid bias.
16. Repeat the above, using a grid leak and grid condenser as a grid bias.

CHAPTER 16

The Regenerative Detector

Problem 1: *What are the principles of the regenerative system in the detector?*

Problem 2: *How are the faults of this system corrected?*

Problem 3: *How can we build a practical receiving set with a "feedback" system?*

At this point in the development of the science of radio, there arose a tremendous desire for increased sensitivity in the receiving sets. The thrill of hearing a faraway radio station entranced amateur and professional alike. The hue and cry was for more "DX" (long-distance) reception.

96. The Feedback Circuit

This demand was satisfied by giving a new twist to the triode detector receiving set. We now call this device the *regenerative* or *feedback circuit*. Here is how it works.

When we considered the tuning circuit, you learned that there were two streams of electrons oscillating through that circuit in step with each other. One was the stream set flowing by the discharge of the tuning condenser. The other was the stream set flowing by mutual induction from the aerial-ground system.

Theoretically, the oscillations of the electrons in the tuning circuit should have continued to build up or gain in strength indefinitely. Actually, however, the resistance in the circuit limited the degree to which these oscillations could be built up. So you see there are two reasons for reducing the resistance against current flow in the tuning circuit. One, as you know, is to make our set more selective. The other is to build up the oscillations of electrons. With less resistance a greater current will flow and therefore a weak impulse from a distant station will be built up to the point where we can hear it in our phones.

Try as we may, however, we cannot completely eliminate the resistance from our circuit. A certain minimum will always remain. This minimum can be made small enough so that it does not interfere with the selectivity of the set, but it will always remain large enough to limit the degree to which we can build up the oscillations in the tuning circuit.

An American scientist, Major E. H. Armstrong, conceived the idea of causing a third stream of electrons to flow in the tuning circuit in step with the other two. This third stream supplied the electrical energy to overcome the resistance in the circuit and now the oscillations could build up to a very high degree.

He accomplished this by causing the plate current to flow through a coil of wire called a *plate coil* or *tickler*. This plate coil was placed in close proximity to the secondary of the antenna coupler. When the plate current flowed through the plate coil, a magnetic field was created around this coil. This field cut across the turns of the secondary of the antenna coupler and set a stream of electrons flowing in the tuning circuit just as did the primary of the antenna coupler.

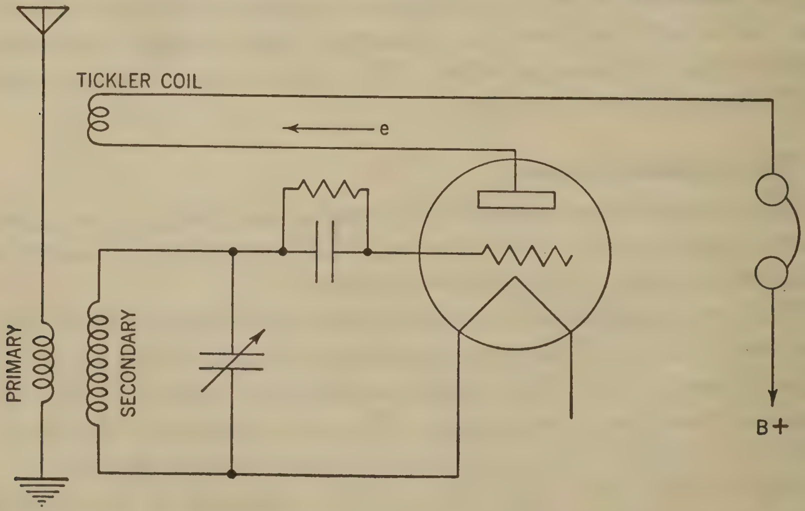


Figure 74. Diagram showing how plate current is fed back to the tuning circuit by means of the tickler coil.

So you see, current from the plate circuit has been *fed back* to the tuning circuit. The fluctuating direct current flowing through the tickler coil sets up an alternating current in the secondary of the antenna coupler by transformer action (Figure 37-A). Since the variations in the plate current were produced by the variations of current flowing in the tuner, the two currents are in step.

This arrangement of the three coils is sometimes called a *three-circuit tuner.*

However, the oscillations of electrons in the tuning circuit were built up so well that another problem presented itself.

97. The Receiver Becomes a Transmitter

It was stated in Chapter 3 that if electrical pulses are sent through a circuit 10,000 times or oftener per second, a radio wave is created. Here, now, electrical pulses are being sent through the tuning circuit tens of thousands and perhaps millions of times per second. Under normal conditions the oscillations of electrons in the tuning circuit are too weak to cause any damage. But now, because the resistance of the tuning circuit has been overcome, these oscillations are built up to a point where a strong radio wave is created and our receiving set becomes a transmitting station.

This radio wave interferes with the incoming signal and causes clicks, whistles, and howls in our phones. Some of you may remember the early days of the regenerative receiver. You may remember how frequently these howls and whistles occurred. And you may remember receiving these howls and whistles from receiving sets as far away as several blocks!

When the oscillations become too strong and the receiving set becomes a transmitter, we say the set *oscillates* or *spills over.* The trick, then, is to permit the oscillations in the tuning circuit to build up to a point just before the set starts to oscillate. It is at this point that we get our loudest, undistorted signal.

98. Controlling the Oscillations by Moving the Tickler Coil

This limitation is usually accomplished by one of three methods. First, there is the method of controlling the efficiency of the feedback action. If we place the tickler coil further away from the secondary of the antenna coupler the electrical energy transmitted by mutual induction becomes smaller. This means that a smaller stream of electrons is set flowing in the tuning circuit. The trick is to set a stream of electrons flowing which will just fail to overcome the resistance of the tuning circuit. It is this excess resistance that will prevent the oscillations from being built up too much.

The same effect is accomplished by changing the angle which the tickler coil makes with the secondary of the antenna coupler. When the two coils are parallel you get the maximum feedback. When the two coils are at right angles, you get the minimum feedback. By making the angle adjustable, you are able to get the

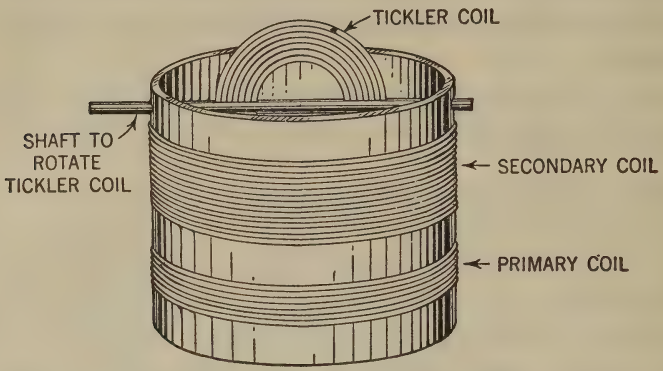


Figure 75. Three-circuit tuner showing arrangement to vary the coupling between the secondary coil and the tickler coil.

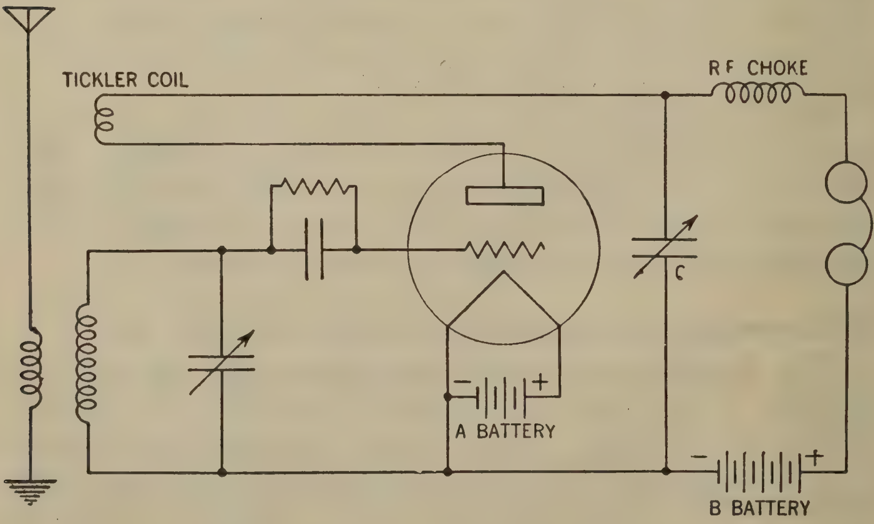


Figure 76. Three-circuit tuner using a variable condenser (C) to control the amount of feedback. The inductance marked "R. F. Choke" is a small coil of wire used to direct the plate current into the tickler coil.

desired amount of feedback. When we use this method of controlling the feedback we say that we vary the *coupling* between the two coils.

99. Controlling by a Variable Condenser

Another method is to utilize a *variable condenser* connected as shown in Figure 76. Now some of the electrical energy flowing in the plate circuit is used up to place a charge on this condenser. This means that there is less electrical energy left to be fed back to the tuning circuit. By varying the size of the condenser, you can vary the amount of electrical energy drained away and thus control the amount of energy to be fed back to the tuning circuit. The variable condenser used is usually the same size as the one used in the tuning circuit.

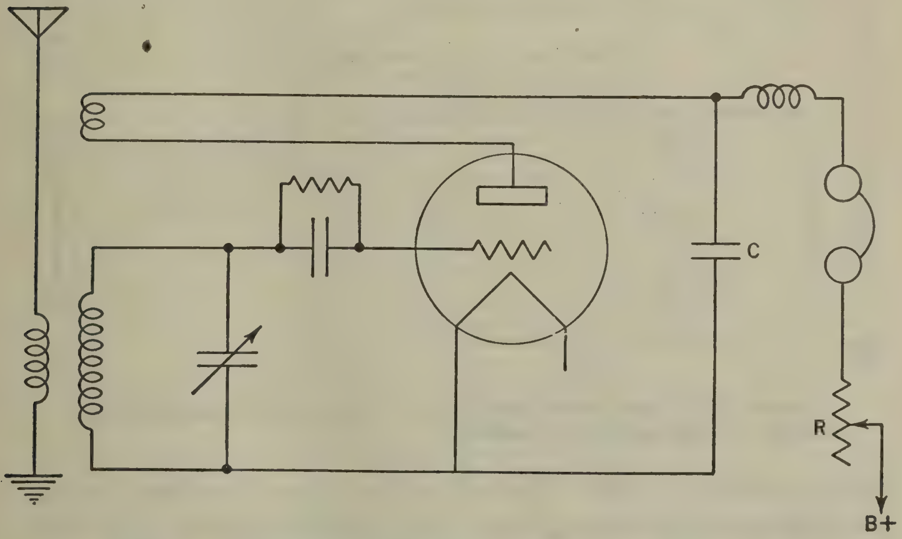


Figure 77. Three-circuit tuner using a fixed condenser (C) of about .00025 microfarad and a rheostat (R) of about 50,000 ohms to control the amount of feedback.

100. Using a Fixed Condenser and a Rheostat to Control the Feedback

The third method is to substitute a *fixed condenser,* whose value is usually about .00025 μfd., for the variable condenser described above. We now control the amount of electrical energy fed back to the tuner by placing our old friend, the *rheostat,* in the plate circuit, as shown in Figure 77. This rheostat, usually of about 50,000 ohms value, controls the total amount of current flowing in the plate circuit. Since a constant amount of electrical energy is drained off by the fixed condenser, the variation in the total electrical energy in the plate circuit will determine how much will be fed back to the tuner. Since, by means of the rheostat, we can vary the current in the plate circuit, we have a means for controlling the feedback current.

Another variation using the rheostat to control the amount of feedback is merely to place a 50,000-ohm rheostat across the tickler coil as in Figure 78. Now the current flowing in the plate circuit has two paths to follow. Part of it flows from the plate, through the rheostat and into the phones. None of this current is fed back to the tuner. The rest goes through the tickler coil and is fed back to the tuning circuit. The greater the resistance of the rheostat, the less current can flow through it and the more current flows through the tickler coil; and therefore, the more electrical energy is fed back. Thus by varying the resistance by means of the rheostat, you can vary the amount of feedback.

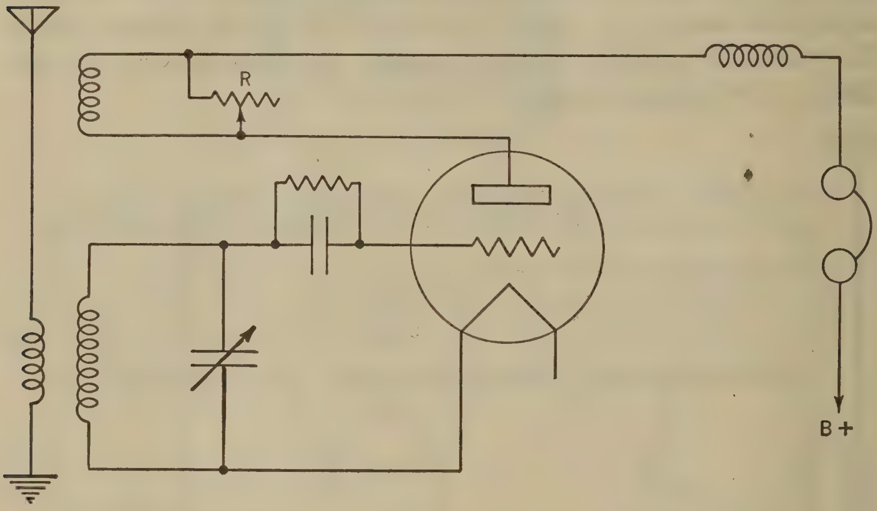


Figure 78. Three-circuit tuner using a rheostat (R) of about 50,000 ohms to vary the amount of feedback.

101. Building a Regenerative Receiver

These three controls of feedback—the coupling control (Figure 75), the variable condenser (Figure 76), and the rheostat (Figures 77 and 78), are called *regenerative* or *feedback controls.*

If you wish to build a regenerative set, here is how to make the coils. Obtain a cardboard mailing tube about 2 in. in diameter and about 6 in. long. At about ½ in. from one end drill a fine hole with a pin or needle. Thread in about a foot of No. 28 gauge double cotton-covered copper wire. This is to anchor the winding. Now wind on 15 turns of this wire, placing the turns next to each other. Anchor this end and all the ends of the other two coils the same way as above. This is your tickler coil. Look at Figure 79 to see that you have the right idea for winding the coils.

About ⅛ in. from the bottom of the tickler, start winding the secondary of the antenna coupler. Note that all three coils must be wound in the same direction. Wind on 90 turns of wire.

About ⅛ in. from the bottom of the secondary coil, wind on 15 turns for the primary of the antenna coupler.

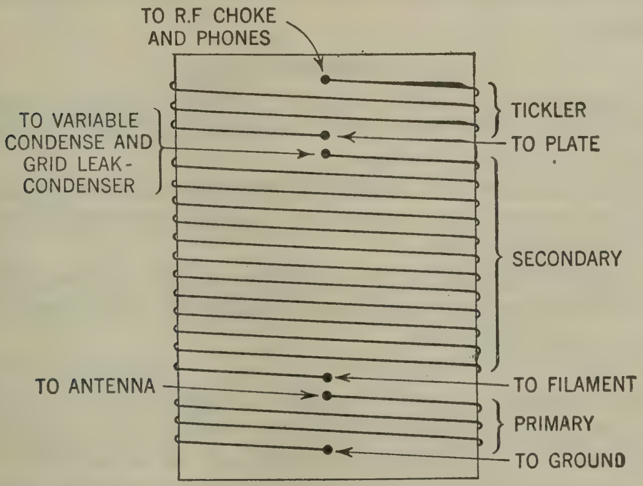


Figure 79. Diagram showing construction and connections of the three-circuit tuner.

102. Connecting the Parts

Now connect the top of the tickler coil to the R. F. choke and phones and the bottom of this coil to the plate of the tube. Refer to Figures 76, 77, 78, and 79. The top of the secondary of the antenna coupler goes to one end of the variable tuning condenser (usually the stationary plate terminal), and the grid leak and grid condenser. The bottom of this coil goes to the other end of the variable tuning condenser (usually the rotary plate terminal) and the filament of the tube.

The top of the primary coil of the antenna coupler goes to the antenna, the bottom to the ground.

Here is how you operate the regenerative receiver. First tune in your station just as you would on any other set. Now rotate your regenerative control. The signal will get louder and louder until a point is reached where you will hear clicks, whistles, or howls. Now turn your regenerative control back to just before that point is reached. Your set is now tuned in for most efficient reception.

We have now traced the development of radio receivers to a point where we have made a set that is both selective and sensitive. The crystal detector has been replaced by the more stable and efficient triode. Reception is not perfect yet, but millions of radio fans all over the world, sitting up in the small hours of the night, have listened over such radio receivers to that much desired "DX" station.

SUMMARY

1. The **regenerative principle** was added to radio receiving sets to provide greater sensitivity in radio receivers and hence the possibility of receiving more distant stations.

2. This regenerative or **feedback** principle depends upon a third coil, connected to the plate circuit, but coupled inductively to the secondary of the tuning circuit.

3. The electron stream in the secondary of the antenna coupler set flowing by the **tickler coil** oscillates in step with the incoming impulses and builds up their strength.

4. The fault of the regenerative system is its tendency to produce whistles in the phones by oscillating like a transmitting station.

5. This tendency to oscillate may be controlled by (a) a movable tickler coil; (b) by connecting the tickler coil in series with a variable condenser; (c) by using a fixed condenser in combination with a rheostat; (d) by using a rheostat across the tickler coil.

GLOSSARY

Coupling: The degree to which electrical energy is handed on from one circuit to another.

Grid coil: The coil which is connected in the grid circuit of the tube. As discussed in this chapter the grid coil is the secondary of the antenna coupler.

Grid return: The wire connecting the end of the grid coil with the filament of the tube.

Oscillate: The condition under which the electrons flowing in the tuning circuit of the receiver cause it to become a transmitter of radio waves.

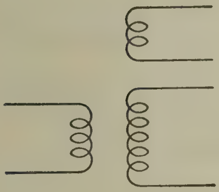
Plate coil or Tickler: The coil which is connected in the plate circuit of the tube.

Regeneration: The action whereby electrical energy in the plate circuit is fed back to the grid circuit to be amplified again and thus produce a louder signal in the earphones or loudspeaker.

Regenerative control: The device by which the amount of electrical energy fed back to the grid circuit is controlled, thus preventing the receiver from oscillating.

Three-circuit tuner: A tuner coupled to the plate circuit as well as to the aerial-ground system.

SYMBOLS



The three-circuit tuner.

QUESTIONS AND PROBLEMS

1. What factor acts to reduce and finally squelch the oscillations of electrons in a tuning circuit?
2. Where does the tickler obtain the energy to feed back to the tuned circuit?
3. Explain how direct current flowing in the tickler produces additional energy in the tuning circuit where alternating current is flowing.
4. Under what circumstance will a receiver act as a transmitter?
5. Describe three methods of regeneration control.
6. Draw a diagram of the coil used for a regenerative receiver, indicating the points for connecting of the coils.
7. What is the purpose of a regenerative control?
8. How do you tune a regenerative receiver for a station?

CHAPTER 17

The Audio-frequency Amplifier

Problem 1: *Why is an amplifier necessary in that part of the circuit in which the earphones are connected?*

Problem 2: *What are the principles of the audio-frequency amplifier?*

Problem 3: *What are the practical applications of audio-frequency amplifiers?*

Although our radio set has been developed to the point where it can bring in weak or distant stations and separate out the unwanted ones, it still has a serious drawback. We still have to use earphones. Not only is it a nuisance to wear them but, moreover, only the person who has them on his head can hear the radio program.

103. The Audio-frequency (A.F.) Amplifier

To meet this objection the audio-frequency amplifier was developed.

You already know how we can attach a large paper cone to the diaphragm of the earphone and thus get a louder sound. But in order to move this large cone we must have more electrical power than ordinarily comes out of the detector. It becomes necessary to amplify or build up the electrical current flowing out of the detector before it can properly operate the loud speaker.

The triode furnishes us with the means for this building up. You know that a small current, placing electrical charges on the grid of the tube, will cause a much larger plate current to flow. This plate current closely follows the fluctuations and variations of the current being fed into the grid, and thus we get out of the tube a much greater current than was put into it, while all the fluctuations are retained in their proper proportions. The signal coming out of the tube will accordingly be the same as the signal fed into it except that it will be much louder. Of course, you know that the B battery supplies the extra power.

All we have to do, therefore, is to feed the plate current from our detector tube into the grid of another tube. The plate current flowing from this second tube will then be our amplified signal.

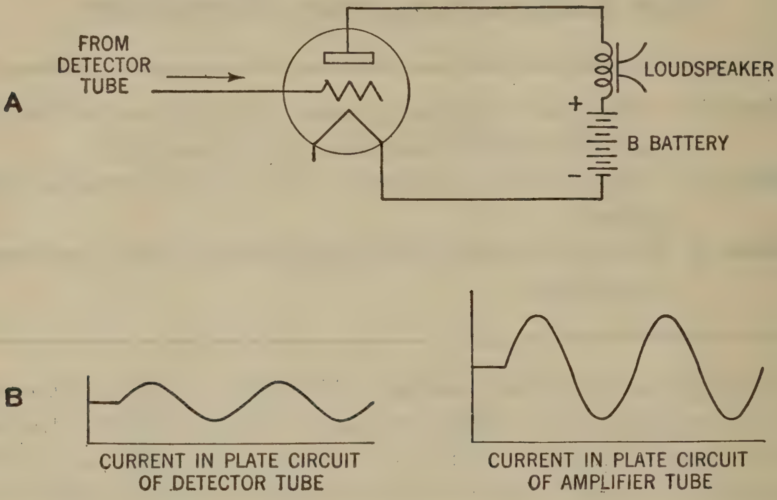

A
FROM DETECTOR TUBE
LOUDSPEAKER
+
B BATTERY
-
B
CURRENT IN PLATE CIRCUIT OF DETECTOR TUBE
CURRENT IN PLATE CIRCUIT OF AMPLIFIER TUBE

Figure 80. A—Audio amplifier showing how signal from the detector tube is fed to the grid of the audio-amplifier tube. B—Graph showing relationship between current flowing in the plate circuit of the detector tube and current in plate circuit of amplifier tube.

This second tube is called the *amplifier tube.* Theoretically, all we need is one such amplifier tube to give us the additional power required to operate the loudspeaker. In practice, however, we find that there are certain factors which limit the amplification possible with one tube. We therefore usually repeat the whole process, using a second amplifier tube to build the signal up still more to a point where the current will be strong enough to operate the loudspeaker. Each time we amplify the signal by the use of an additional triode we say we add one *stage of amplification.* Usually, two stages of amplification are required.

The electrical current flowing in the aerial-ground system and the tuning circuit is radio-frequency current. That is, it alternates millions of times per second. When this current comes out of the detector, it consists of a series of pulses. These pulses, too, occur millions of times per second, that is, at radio frequency. But when you examine Figure 55, you see that the current flowing through the phones is fluctuating at a much slower rate. A series or train of the fast pulses or fluctuations have combined to make one slow fluctuation or pulse.

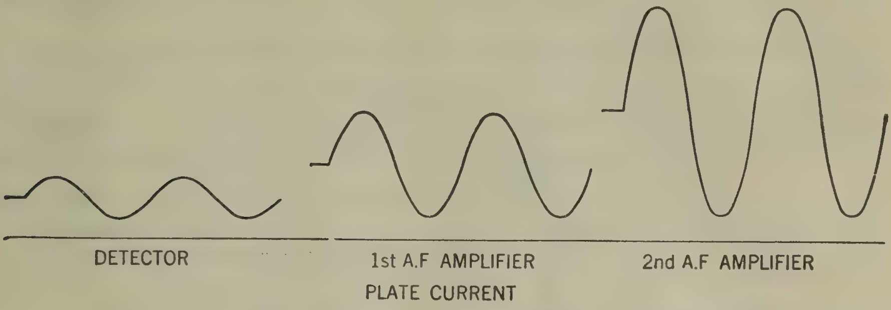


Figure 81. Graphs showing plate current in the detector, the first audio amplifier, and the second audio amplifier.

It is this slow fluctuation which moves the diaphragm and thus produces the sound we hear. We therefore say that this slow fluctuation is at *audio frequency*. The range of audio frequency is from about 30 to 15,000 cycles per second.

Inasmuch as we are now amplifying our signal after it passes out of our detector (after it is changed from radio frequency to audio frequency), we call the amplifier tubes *audio-frequency amplifiers*.

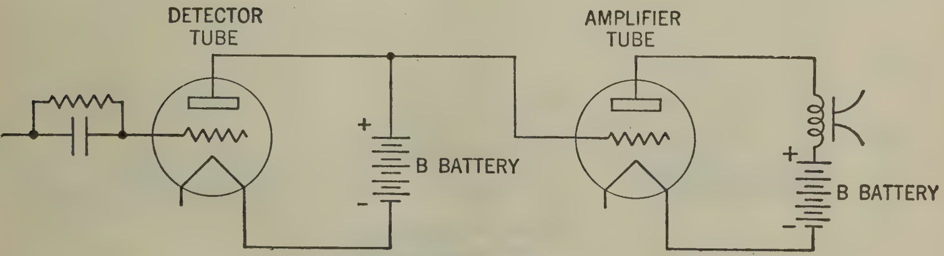


Figure 82. Diagram showing plate of detector tube connected to the grid of the amplifier tube.

104. Methods of Coupling

The next thing to consider is how to feed the current flowing in the plate circuit of the detector tube into the amplifier tube. This is called *coupling*. Look at Figure 82. You will see that the grid of the amplifier tube is connected to the plate of the detector tube.

A difficulty will immediately be noticed. The large B battery of the detector tube, connected directly to the grid of the amplifier tube, will place a large positive charge on that grid and thus the fluctuations of plate current will be blanketed out and no signal will pass. A method must be devised that will pass on the fluctuations of plate current and yet be able to keep out the large positive charge of the B battery.

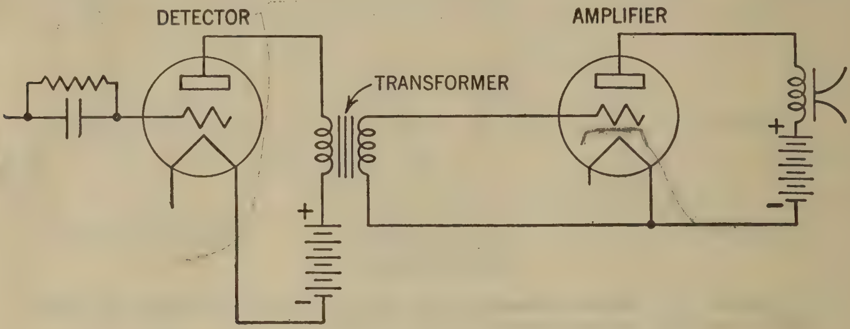


Figure 83. Diagram showing how the detector is coupled to the A. F. amplifier by means of a transformer.

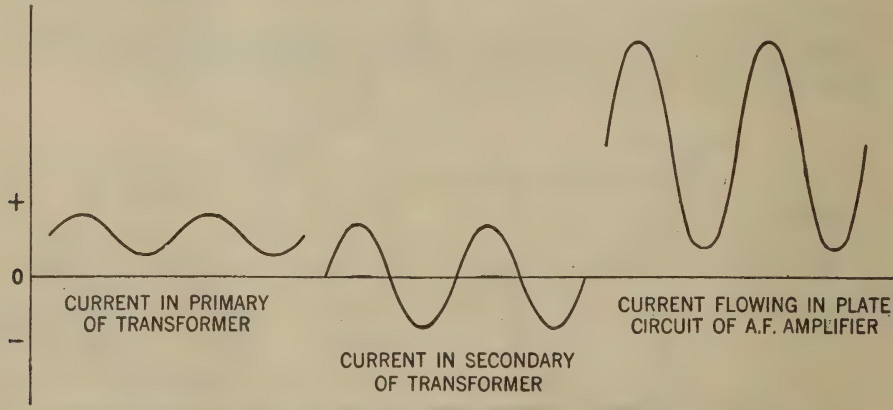


Figure 84. Graphs showing current flowing in primary and secondary of the transformer and in the plate circuit of the A. F. amplifier. Note that the shape of all three curves is the same although the amplitudes vary.

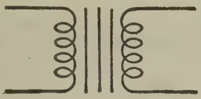
105. We Use a Transformer

Here, again, we call upon our old friend the transformer. We connect the primary in the plate circuit of the detector tube and the secondary in the grid circuit of the amplifier tube. (See Figure 83.)

Now the fluctuating plate current in the primary will set up an alternating voltage or electrical pressure in the secondary. This voltage will fluctuate in step with the fluctuations of plate current (Figure 37-A).

This fluctuating voltage will place fluctuating positive and negative charges on the grid of the amplifier tube and this, in turn, will control the plate current flowing in the plate circuit of the amplifier. This plate current in the amplifier tube will have the same form as the plate current in the detector tube, but will have a greater amplitude, indicating greater power.

Because these currents are audio-frequency currents, we are able to utilize the greater efficiency of an iron-core transformer. The symbol for such a transformer is:



In addition, we are able to utilize the advantages of a step-up transformer. This gives us an additional amplification of the signal. In practice, it has been found that the maximum step-up permissible is about 1 to 5, that is, the secondary has about five times as many turns as the primary. Any greater step-up results in distortion and other losses.

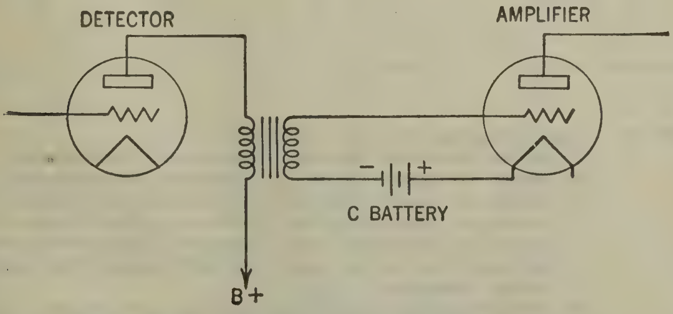


Figure 85. Diagram showing how a C battery is connected in the grid circuit of the amplifier tube.

106. Avoiding Distortion by Grid Bias

We must keep in mind that the amplifier must not only magnify the signal, but must reproduce it in its original form. In other words, there must be a minimum of distortion. One serious objection to our amplifier, as shown in Figure 83, is that when the grid of our amplifier tube becomes positively charged, it will attract some of the electrons streaming from the heated filament and a current will flow in the grid circuit of the tube. This will produce distortion.

To overcome this defect, a C battery is placed in the grid circuit. This battery places a negative *charge* or *bias* on the grid of the amplifier tube and thus prevents the flow of grid current.

This grid bias keeps the grid negative at all times and the negative and positive charges placed on the grid by the alternating voltage across the secondary of the coupling transformer makes the grid more or less negative. (See Chapters 37 and 38 in Vol. II.)

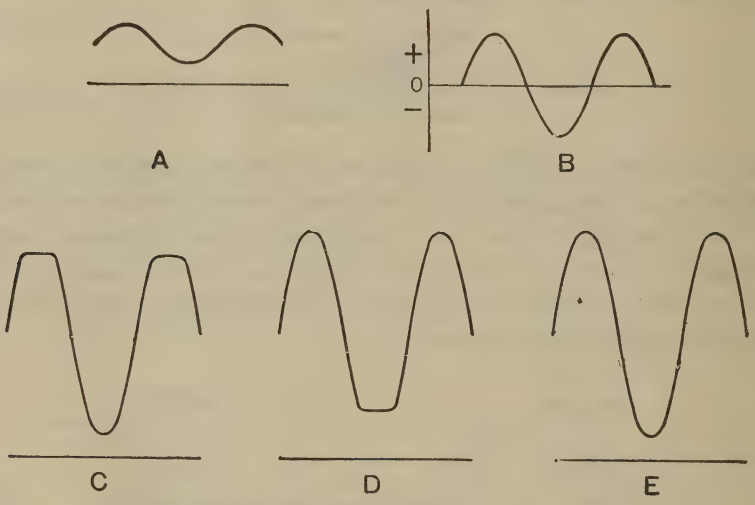


Figure 86. Graphs showing effects of grid bias.
A—Graph of current flowing in primary of transformer.
B—Graph of current flowing in secondary of transformer.
C—Graph of current flowing in plate circuit of amplifier tube when grid bias is too low. A large positive charge on the grid drives it positive and it attracts electrons which would normally flow to the plate. A grid current flows and this causes distortion.
D—Graph of plate current when grid bias is too high. A large negative charge drives the grid so far negative that all the electrons are repelled and no plate current flows. This, too, causes distortion.
E—Graph of current flowing in the plate circuit of amplifier tube when grid bias is just right. Note that the wave form corresponds to that of Figure A.

Another precaution must be taken. In the amplifier tube, unlike the detector tube, the negative charges placed on the grid by the transformer must be prevented from driving the grid so far negative as to cut off the flow of plate current. Such a situation would lop off part of the bottom loop of our curve and distortion would arise (Figure 86-D).

107. Standard Tubes and Grid Bias

Manufacturers of tubes furnish charts showing the proper value of grid bias to be used with their tubes. Thus, if we use an R.C.A. type 01A tube as an amplifier with a plate battery of 135 volts, the C battery, or bias, must be — 9 volts.

You may see from the above data that we can use B batteries of much greater power than are used in the detector circuit. Thus greater plate current, with enough power to operate the loud speaker, will be possible.

108. How to Couple the Audio-frequency Transformer

This method of coupling one tube to another is called *transformer coupling.* The transformer used is called an *audio-frequency transformer.* The primary winding has two terminals marked P and B +. The P terminal is connected to the plate of the detector tube, while the B + goes to the positive terminal of the B battery. The secondary winding also has two terminals marked G and F —. The G terminal is connected to the grid of the amplifier tube while the F — goes to the negative post of the C battery.

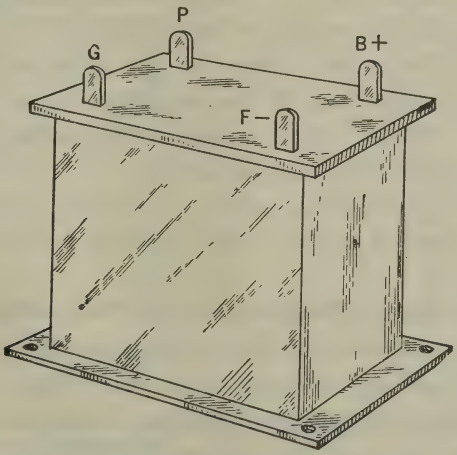


Figure 87. The Audio-frequency Transformer.

There is another method used to couple one tube with another.

A fixed condenser is inserted between the plate of the detector tube and the grid of the amplifier tube (Figure 88).

109. Use of a Coupling Condenser

Now the stream of electrons flowing in the plate circuit of the detector tube divides at point x. Some flow to the positive post of the B battery, while others pile up on plate 1 of the condenser.

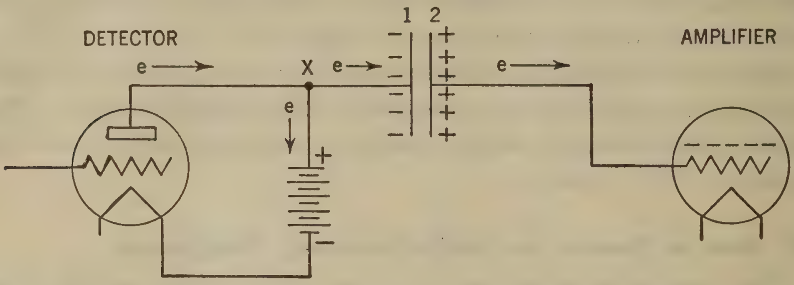


Figure 88. Diagram showing how a fixed condenser is used to couple the amplifier tube to the detector.

Thus a negative charge is placed on this plate. This negative charge drives electrons away from plate 2 of the condenser, leaving a positive charge there. The electrons thus driven away pile up on the grid of the amplifier tube, making that grid negative. Fluctuations in the plate current of the detector tube thus cause a fluctuating negative charge to be placed upon the grid of the amplifier tube. This in turn causes a fluctuating current to flow in the plate circuit of the amplifier tube.

This fixed condenser is called a *coupling condenser.* It has mica for its dielectric and its value is usually about .006 μfd.

110. Why We Need a Resistor in the Plate Circuit

But we have the B battery in the plate circuit of the detector tube to contend with. Because of its large size, the positive post has a very large deficiency of electrons. Thus, unless some means is found to prevent it, all the electrons flowing in the plate circuit of the detector tube will be attracted to it and none will be left to place a negative charge on the condenser.

To meet this difficulty a resistor (Figure 89) is placed between the positive post of the B battery and point x.

This resistor (R) retards the flow of electrons to the positive post of the B battery and thus forces some of the electrons flowing in the plate circuit to flow to plate 1 of the condenser. This resistor is called a *plate resistor* and is usually about 100,000 ohms.

As in the case of transformer coupling, a C battery is placed in the grid circuit of the amplifier tube to prevent the flow of grid current which would cause distortion.

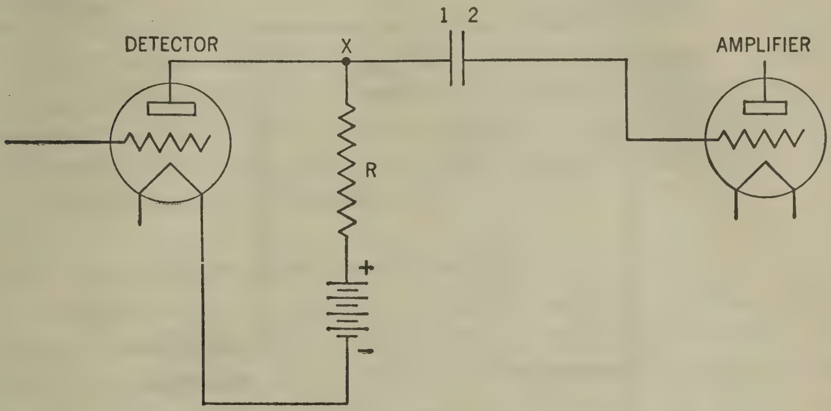


Figure 89. **Diagram showing how plate resistor (R) is placed in the circuit.**

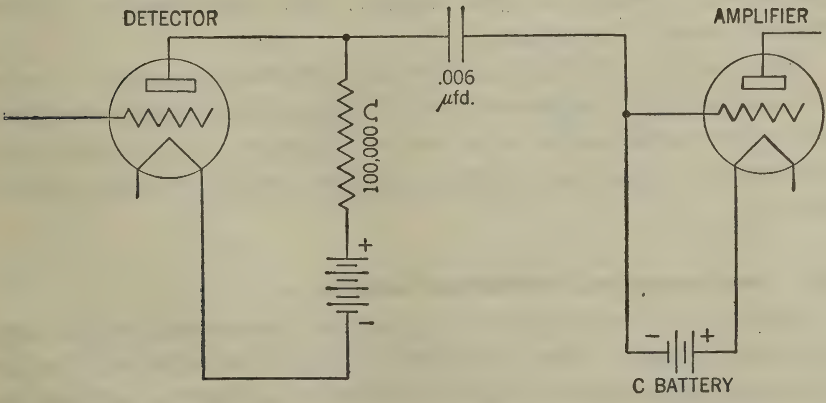


Figure 90. **Diagram showing how the C battery is connected in the grid circuit of the amplifier tube.**

111. A Grid Resistor also Is Needed

But there is still another difficulty to overcome. We are dealing with loud signals, which means that the stream of electrons may be very large. Thus it becomes possible that the stream of electrons set flowing from plate 2 of the condenser may make the grid of the amplifier so negative as to completely cut off the flow of electrons from the heated filament to the plate.

To meet this difficulty a path is provided for these electrons to leak off slowly from the grid to the filament. A resistor is placed in the grid circuit between the C battery and the grid.

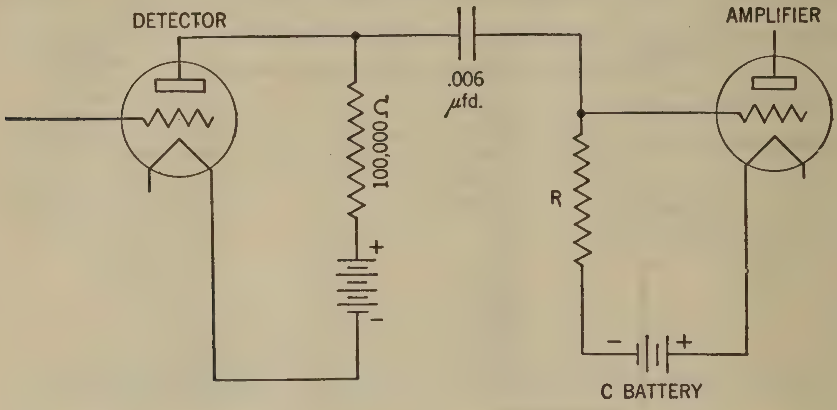


Figure 91. Diagram showing how grid resistor (R) is placed in the circuit.

This resistor is called the *grid resistor.* Its value usually is about 2,000,000 ohms (2 megohms).

This method of coupling is called *resistance coupling.* As in the case of the transformer-coupled amplifier stage described above, this amplification is at audio frequency and it is therefore described as a stage of *resistance-coupled audio-frequency amplification.*

112. Transformer vs. Resistance Coupling

Each of the two methods of coupling has certain advantages and disadvantages. The transformer method of coupling has the advantage that, stage for stage, it will give a greater amplification than does the resistance method of coupling. Two stages of transformer-coupled audio-frequency amplification are about equal to three stages of resistance-coupled audio-frequency amplification. The need of fewer stages with the transformers than with the resistors is due to the amplification resulting from the use of step-up transformers.

Further, we need a less powerful B battery with transformer coupling than is needed with resistance coupling to obtain the same plate current. This difference is due to the fact that the large resistor used for a plate resistor in the resistance-coupled audio-frequency amplifier cuts down the amount of positive charge that the B battery can place on the plate of the tube.

Still another advantage is the simplicity of the transformer-coupled stage. Only one part is needed for the coupling, the audio-frequency transformer.

The resistance-coupled amplifier has the advantage in that it reproduces the signal more faithfully. The audio-frequency transformer usually introduces a certain amount of distortion. Another advantage is that resistance coupling is cheaper and lighter than the audio-frequency transformer.

113. The Audio-frequency Amplifier Unit

In considering the radio receiving set as a whole, the several stages of audio-frequency amplification are usually treated together as a separate unit. In fact, in some modern receivers this unit is built separately and apart from the rest of the set. As previously stated, this unit may consist of two stages of transformer-coupled or three stages of resistance-coupled amplification.

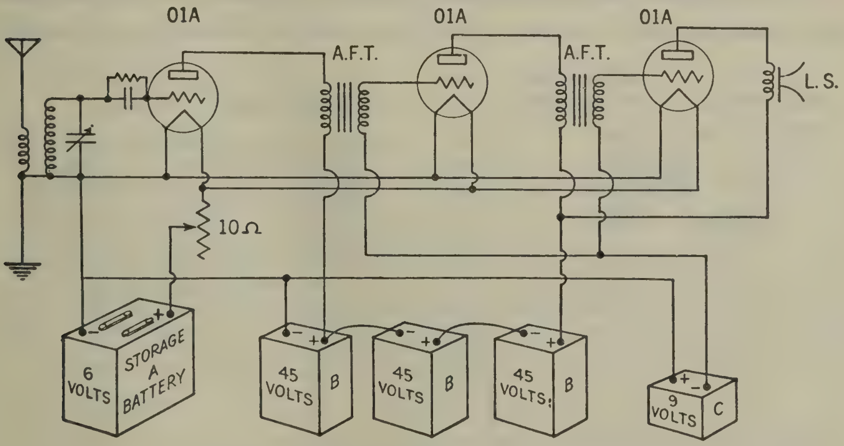


Figure 92. Diagram showing detector and two stages of transformer-coupled audio-frequency amplification.

Often the two systems are combined, with one or two stages of resistance-coupled amplification followed by a stage of transformer-coupled amplification.

It is impractical to use more than two stages of transformer-coupled or three stages of resistance-coupled amplification. If we do, we may encounter serious distortion of the signal. Besides, for normal use, more amplification is not necessary.

In Figure 92, we have a detector followed by two stages of transformer-coupled amplification.

The tubes used are triodes of a type known as 01A. Instead of using separate A batteries for each tube, the filaments of the tubes are hooked together in parallel and connected to a single battery supplying 6 volts. The rheostat used as a volume control now limits the amount of current flowing in the filaments of all three tubes. For this purpose we use a rheostat of 10 ohms.

To obtain the B battery of 135 volts, we connect three 45-volt batteries in *series*. That is, we connect the positive terminal of one to the negative terminal of another. To obtain the 45 volts needed for the detector tube, we make our connections between the negative terminal of the first battery and the positive terminal of this same battery. If, however, we connect between the negative terminal of the first battery and the positive terminal of the third battery we obtain the 135 volts needed for our amplifier tubes.

The C-battery connections of the two amplifier tubes are likewise connected and we now can use a single C battery of 9 volts.

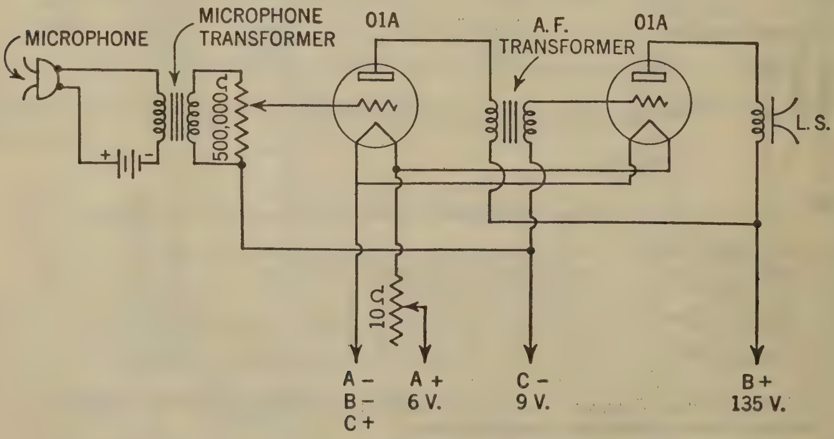


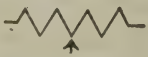
Figure 93. Diagram showing circuit of the public-address system.

114. The Public-address System

We can use the audio-frequency amplifier for other purposes than amplifying a radio signal. Suppose you were to feed an alternating voltage set up by a microphone into the grid of your amplifier tube. You would now have the public-address system used by speakers in addressing large audiences.

The microphone is similar to the telephone transmitter of Figure 11. Speaking into the microphone varies its resistance and thus causes the direct current flowing through the primary of the transformer to vary. The direct current varies in step with the variations of the sound waves created by the speaker.

This fluctuating direct current flowing through the primary of the transformer sets up a varying, alternating voltage across the secondary. This alternating voltage places varying charges upon the grid of the amplifier tube and this variation in turn causes a large, fluctuating direct current to flow in the plate circuit of the tube. After another stage of amplification the current is strong enough to operate the powerful loudspeaker.

The transformer used in a microphone circuit is similar to the audio-frequency transformer used in the radio receiver. However, in connection with it note, in Figure 93, a device that looks like a rheostat across the secondary. This is known as a *potentiometer*. Its use is to limit the amount of charge placed on the grid of the tube and thus control the volume of the amplifier. Its value in this case is about 500,000 ohms. The symbol for a potentiometer is: 

115. The Electrical Phonograph

Still another use for the audio-frequency amplifier is the electrical phonograph. Use is made of the peculiar properties of crystals of a chemical compound known as Rochelle salts. When one of these crystals is squeezed it generates a minute alternating electrical voltage. This voltage varies with the variations in pressure upon the crystal. This phenomenon is known as the *piezo-electrical effect*.

Such a crystal is mounted so that the vibrations of a phonograph needle, traveling in the grooves of a phonograph record, place a varying pressure upon it. In the crystal an alternating voltage is generated that varies in step with this pressure. This voltage is fed to the grid of the amplifier tube, placing a varying electrical charge upon it. This charge in turn causes a fluctuating direct current to flow in the plate circuit of the tube. After another stage of amplification the current is strong enough to operate the loudspeaker. (See Figure 94.)

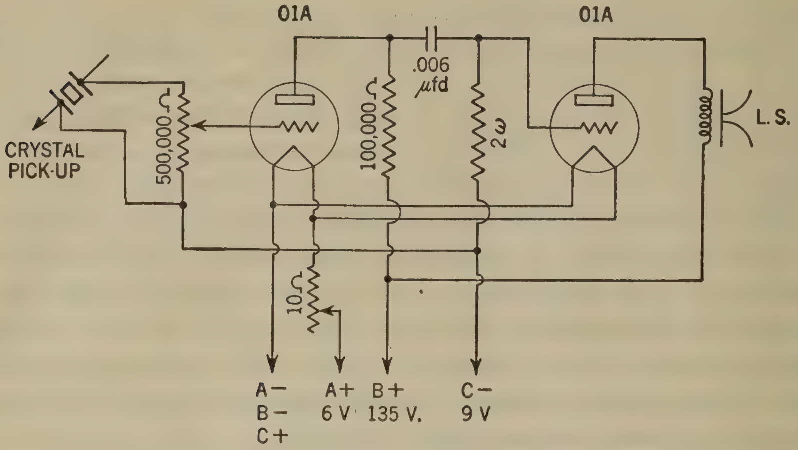
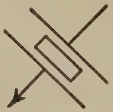


Figure 94. Diagram showing circuit of the electrical phonograph.

The crystal and its mounting is known as a *crystal phonograph pickup*. The symbol for such a pickup is:



Note that no transformer is necessary here to couple the crystal pickup with the tube. The reason is that the voltage generated is alternating voltage and it can be applied directly to the grid of the tube. A 500,000-ohm potentiometer acts as a volume control, just as in the case of the public-address system.

This suggests some uses to which the audio-frequency amplifier can be put. It can be used anywhere that a very small electrical voltage is to be amplified. It has been used successfully with photo-electric cells, in electrocardiograph machines, and the like. Each day brings forth new uses for this wonderful device.

SUMMARY

1. The purpose of the **audio-frequency amplifier** is to increase the intensity (loudness) of the signals so that a loudspeaker may be used instead of earphones.

2. The principle of the audio-frequency amplifier is to connect the plate circuit of a tube to the grid of another tube. The plate current in the second tube will then be an amplified reproduction of the signal in the detector tube.

3. By connecting a third tube in the same manner to the plate circuit of the first amplifying tube a second stage of amplification may be made.

4. Distortion in the amplifying system is prevented by carefully balanced values of grid bias, plate resistors, and capacity.

5. Audio-frequency amplifiers are used for public-address systems, to increase the loudness of phonograph records, for amplifying signals of photo-electric cells, and for many other purposes.

GLOSSARY

Amplifier, audio-frequency: A circuit to amplify the electric currents flowing out of the detector, thereby enabling us to use a loudspeaker.

Amplification, stage of: The tube and its accompanying electrical devices serving as an amplifier.

Audio frequency (A.F.): A frequency in the range between 30 and 15,000 cycles per second.

Audio-frequency transformer: An iron-core transformer used to transfer electrical energy at audio frequencies from one tube to another.

Coupling condenser: A fixed condenser used in a resistance-coupled amplifier to transfer electrical energy from one tube to another.

Grid resistor: A resistor connected in the grid circuit of a tube.

Microphone: A device used to change sound waves to a fluctuating electrical current.

Phonograph pickup: A device used to change variations in a phonograph-record sound-track to a fluctuating electric current.

Piezoelectric effect: The effect whereby pressure on certain types of crystals produces an electric current.

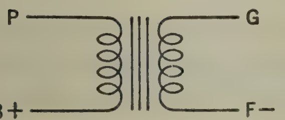
Plate resistor: A resistor connected in the plate circuit of a tube.

Potentiometer: A resistance device enabling us to tap off portions of the entire voltage placed across it.

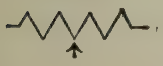
Resistance coupling: Coupling between the plate circuit of one tube and the grid circuit of the next by means of resistors and a coupling condenser.

Transformer coupling: Coupling between the plate circuit of one tube and the grid circuit of the next by means of a transformer.

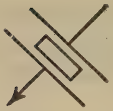
SYMBOLS



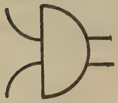
Audio-frequency transformer.



Potentiometer.



Crystal pickup.



Microphone.

QUESTIONS AND PROBLEMS

1. What purpose does an audio-frequency amplifier serve?

2. What part of the tube enables us to use the tube as an amplifier? How does it perform this function?

3. What is the range of audio frequencies?

4. What is meant by "coupling the energy from the plate circuit of the detector to a stage of audio-frequency amplification"?

5. What are the methods for coupling energy from the detector to an audio amplifier?

6. What is the maximum voltage step-up tolerated in an audio-frequency transformer?

7. How does the C battery in a stage of audio-frequency amplification differ from the function of that in a detector?

8. From what source does an amplifier gain the energy required to operate a loudspeaker that needs a great power input?

9. What advantage does transformer coupling have over resistance coupling?

10. What is the function of the coupling condenser?

11. What is the function of the plate resistor?

12. What is the ratio of the number of stages of the transformer-coupled audio-frequency amplification to the number of stages of resistance-coupled audio-frequency amplification?

13. What advantages have resistance-coupled audio-frequency stages over transformer-coupled stages?

14. Why can we not use many stages of audio-frequency amplification?

15. How may a few stages of audio-frequency amplification be used as a public-address system?

16. Explain how a few stages of audio-frequency amplification may be used to make a phonograph player.

17. What is the piezoelectrical effect?

18. Draw a circuit containing a regenerative detector and two stages of audio-frequency amplification, having one stage transformer-coupled to the detector and in turn resistance-coupled to another stage of audio-frequency amplification.

CHAPTER 18

Eliminating the B Battery

Problem 1: *What are the faults of A and B batteries?*

Problem 2: *How is the common alternating current converted into a steady direct current?*

Problem 3: *How is the common alternating current made to deliver higher voltage for the plate and lower voltage for the filament?*

Problem 4: *What are the essential parts of a B eliminator and how does it work?*

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116. Some Faults of Batteries

Having eliminated the nuisance of the headphones, the next problem to be tackled is that of getting rid of the various batteries required. These batteries have several serious drawbacks. They have a limited life, even though the radio receiver be used infrequently. This means periodic replacements which are not only troublesome but costly. Besides, as the batteries start to wear out, the voltage delivered starts to fall off. This deterioration means uneven performance.

Furthermore, the batteries are quite bulky, especially those of the high-voltage type used as plate batteries for the amplifier tubes.

To heat the filaments of the tubes, a storage battery is usually used. This battery must be recharged periodically as the current is used up. Besides this nuisance the storage battery is heavy, bulky, and contains an acid which may be spilled easily with disastrous results to clothing, rugs, and woodwork.

Since the use of house current for lighting purposes is fairly universal, it was only natural to seek a means of using this house current to replace the batteries.

117. The Diode as a Rectifier

The first battery to be eliminated was the plate or B battery. The house current most widely used in our country is alternating current with a voltage or electrical pressure of 110 volts. This alternating current usually has a frequency of 60 cycles per second.

Such an alternating current cannot be applied directly to the plate of the tube because this plate must always have a steady positive charge. Any fluctuations of the positive charge on the plate due to variations in the plate battery voltage would result in distortion of the signal. It becomes necessary, therefore, to change the alternating current of the house line to a steady direct current before it can be fed to the plate of the tube.

You will recall that the diode tube changes alternating current into pulsating direct current. So we feed the alternating current of the house line into a diode tube as in Figure 95.

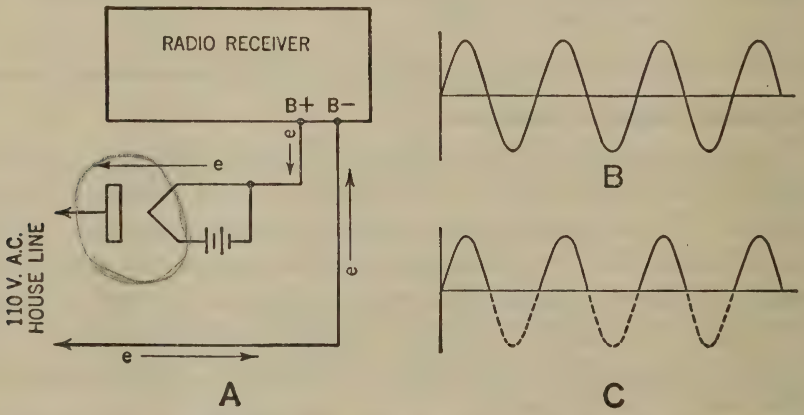


Figure 95. A—The diode as a rectifier tube. For the sake of simplicity the circle around the symbol for the diode is omitted.
B—Wave form showing alternating current flowing in house line before rectification.
C—Wave form showing the alternating current after it has been rectified by the rectifier tube. The bottom half of the loop has been cut off and the current now becomes a pulsating direct current.

When the plate of the diode has a positive charge on it, current will flow from the house line to the plate circuits of the radio receiver. When a negative charge is placed on the plate of the diode, no current will flow. A diode used as indicated here is called a *rectifier tube.* We say that we have *rectified* the alternating current.

118. The Filter System

But it is not enough to change the house current from alternating current to *pulsating* direct current. We must change it to a *steady* direct current. To do this we must pass the pulsating direct current through a *filter.*

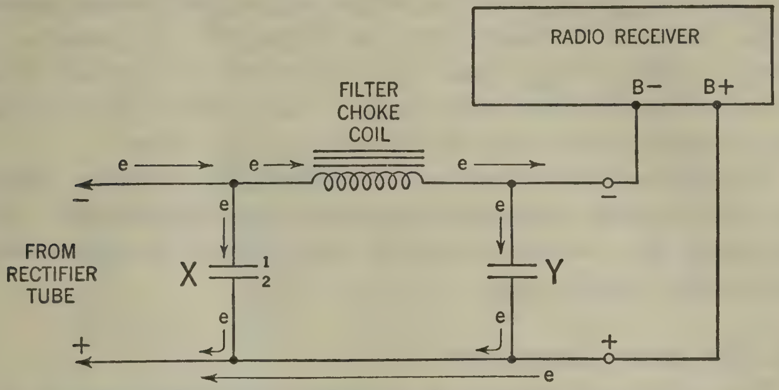


Figure 96. Hookup showing the filter system.

In Figure 96, you will notice that the pulsating direct current from the rectifier tube is fed into a network consisting of two condensers (X and Y) and an iron-core inductance. This inductance contains many turns of wire and is called a *filter choke coil.* An inductance of 30 henries is usually used.

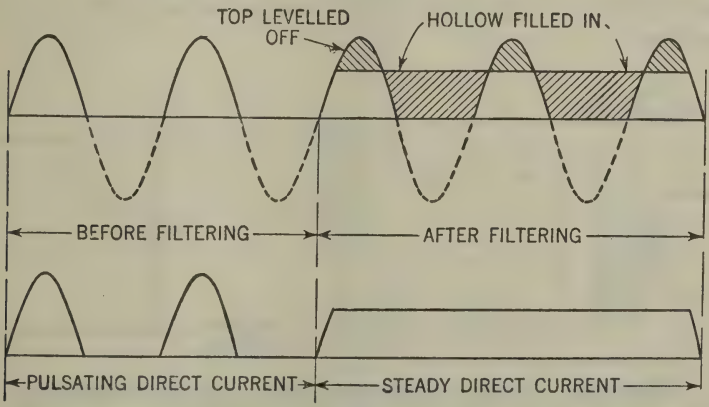


Figure 97. Wave form showing how the filter system changes pulsating direct current to steady direct current.

As the electrons rush up to the choke coil, they encounter a very great resistance resulting from the many turns of wire and the self-inductance of the coil. As a result, they are forced to pile up on plate 1 of condenser X. Here they accumulate until enough of them are piled up to overcome the resistance offered by the coil. Thus condenser X acts as a sort of reservoir or storage tank for the electrons. On the other side of the choke coil, condenser Y also acts as a storage tank for these electrons.

A result of the action of the choke coil and condensers is shown in the graph of the wave form in Figure 96—the peaks of the pulsating direct current from the rectifier tube are leveled off and the hollows are filled in. The result in the receiving set is a steady direct current which is fed to the plates of the tubes.

The action of the filter is to hold back the pulsating electron flow until a steady average flow is reached and maintained. When this steady flow results, we say we have *filtered* the current flowing from the rectifier tube.

119. The Power Transformer

The voltage of the current flowing out of the filter is about the same as the voltage of the house current, namely, 110 volts. As this does not place a very high charge on the plate, someone thought of using a step-up transformer to increase the house-current voltage to about 300 volts. Thus about 300 volts of steady direct current flow out of the filter, and we are able to place a higher positive charge on the plates of the tubes in the receiver; a greater plate current flows and a louder sound comes out of the loudspeaker.

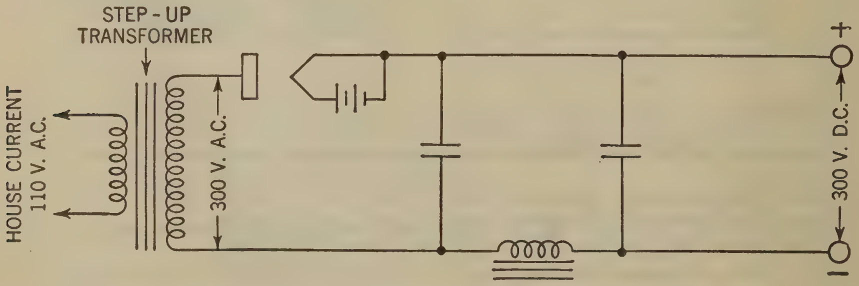


Figure 98. B battery eliminator using a step-up transformer.

In practice, the primary of the step-up transformer is connected to the 110-volt alternating current of the house line. The secondary is connected to the rectifier tube and filter (see Figure 98).

The step-up transformer used here is called a *power transformer.*

120. A Step-down Transformer for the Rectifier

To eliminate the necessity for using a filament battery for the rectifier tube, a step-down transformer is used to step down the 110-volt house alternating current to a value that the rectifier tube requires. If we use a type 81 rectifier tube, the transformer steps down the 110-volt alternating current to 7½-volt alternating current. Using alternating current on the filament of the rectifier tube does not cause any interference with the signal.

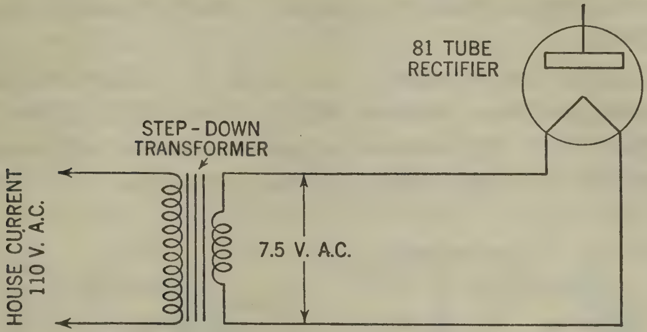


Figure 99. Step-down transformer used to heat the filament of the rectifier tube.

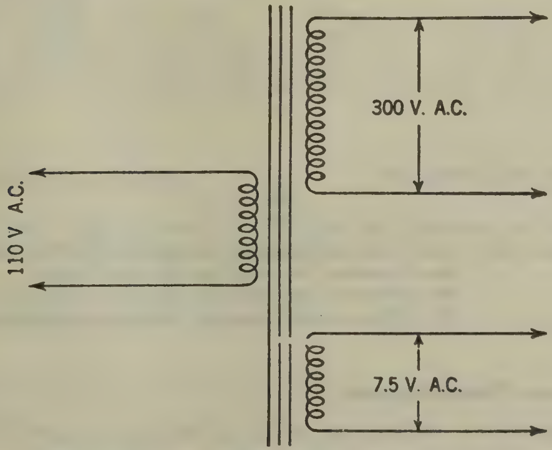


Figure 100. Transformer with two secondaries to step up the voltage for the plate supply and to step down the voltage for the filament of the rectifier tube.

The primary of the step-down transformer is connected to the

110-volt alternating-current line and the secondary is connected across the filament of the rectifier tube in place of the filament battery. The step-down transformer used here is called a *filament transformer.* The wiring diagram is shown in Figure 99.

For convenience, the two secondaries, the step-up to the plate of the rectifier tube and the step-down to the filament, may by suitable winding, be made to operate from the same primary (see Figure 100).

Still another improvement was made to utilize the half cycle of alternating current blocked out by the action of the rectifier tube (Figure 95). By connecting up two rectifier tubes as shown in Figure 101, this half cycle could be put to use.

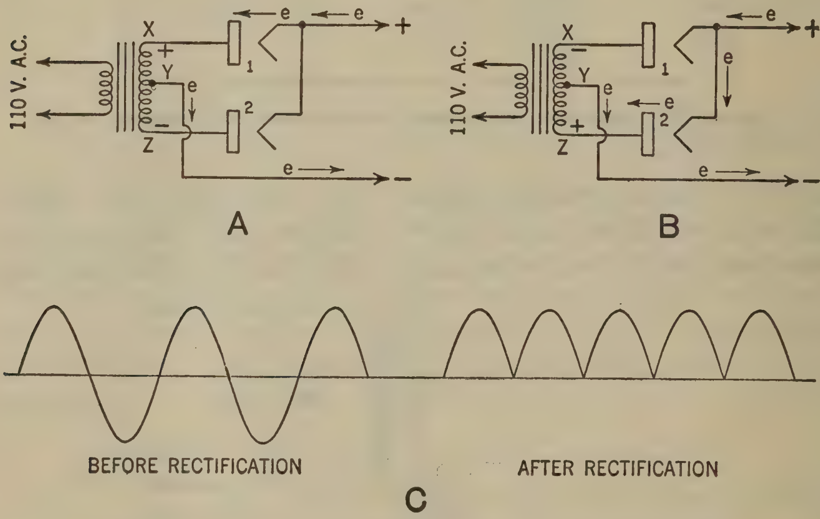


Figure 101. **Full-wave rectification using two rectifier tubes.**
A—Electron flow during one half cycle.
B—Electron flow during the next half cycle.
C—Wave form showing full-wave rectification.

121. Full-wave Rectification

In Figure 101-A, when point X of the secondary of the power transformer has a positive charge on it, point Z has a negative charge. This means that the plate of rectifier tube 1 is positive and the plate of rectifier tube 2 is negative. Electrons then stream from the filament of tube 1 to the plate and through the secondary to point Y, the electrical mid-point of the secondary. Since Z is negative it repels these electrons and they are forced to stream through the wire connecting Y to the filter circuit. Tube 2 does not operate.

During the next half cycle (Figure 101-B) the charges on the secondary are reversed. Now tube 1 does not operate, while electrons from tube 2 stream to point Y and to the filter circuit.

This method of rectification, using both halves of the alternating-current cycle, is called *full-wave rectification.* The method previously described, using only one half of the cycle, is called *half-wave rectification.*

Full-wave rectification is easier to filter because the hollows between the direct-current pulses are smaller (Figure 101-C).

A logical development was to combine the two rectifier tubes into one, using two plates and one filament. In this double tube the filament is constantly emitting electrons, which are attracted first to one plate and then to the other as the charges on these plates are alternately positive and negative.

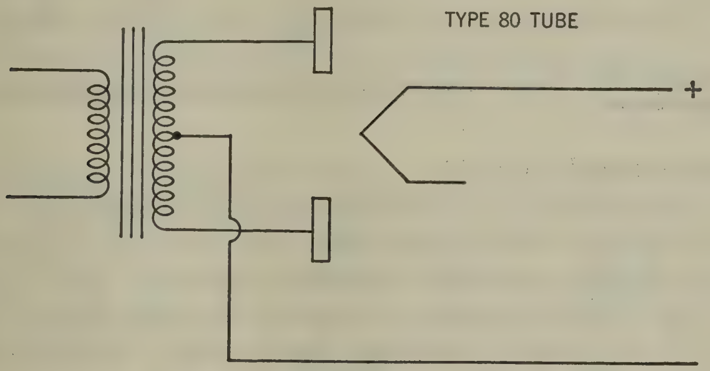


Figure 102. Type 80 rectifier tube with one filament and two plates. This tube is used for full-wave rectification.

An example of a full-wave rectifier tube is the type 80.

122. A Potentiometer Is a Form of Voltage Divider

After full-wave rectification was perfected, one more thing remained to be done. The steady direct current flowing out of the filter circuit was at an electrical pressure of about 300 volts. This voltage is suitable for the plates of the amplifier tubes, but it is too high for the plate of a detector tube, where a maximum of 100 volts is needed. A means had to be devised to enable us to tap off a lower voltage for the detector tube. This object was accomplished by connecting a potentiometer across the output terminals of the filter circuit.

Here is how the potentiometer works. Assume that the electrical pressure at the output terminals of the filter circuit is 300 volts. This statement means that the electrons piled up on the negative terminal are seeking to get to the positive terminal with a force which is equal to this electrical pressure of 300 volts. Electricians call this a *drop* of 300 volts. Now we connect a resistor from the negative terminal to the positive terminal. The electrons use up the 300-volt pressure in traveling the entire length of the resistor to the positive terminal. But the drop, or fall in pressure (technically, the drop in potential) is proportional at any point to the fraction of the resistor which has been overcome at that point.

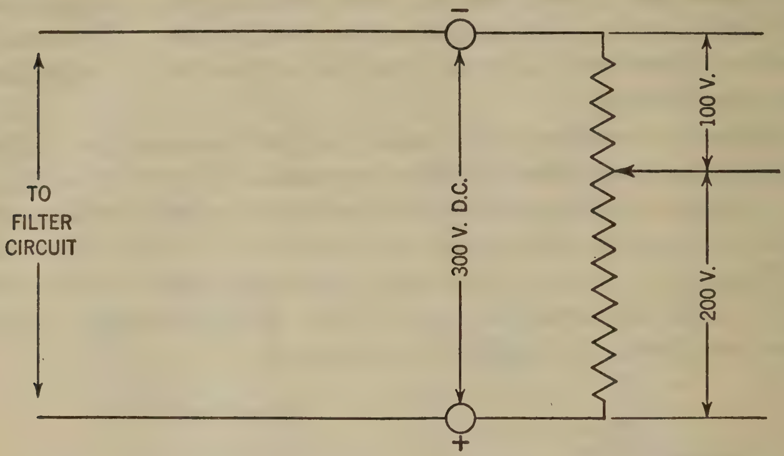


Figure 103. Diagram showing how a potentiometer is hooked up as a voltage divider.

Suppose we take a point one third of the way down the resistor. At this point the electrons have used up one third the pressure and the pressure of the electrons at that point seeking to reach the positive terminal is 200 volts. At a point two thirds of the way down the resistor, two thirds of the original total voltage (or pressure) has been used and the pressure between that point and the positive terminal is only 100 volts. So by moving the slider of the potentiometer from point to point on the resistor we can get any desired voltage out of the filter circuit. The potentiometer, hooked up in this circuit, is called a *voltage divider.*

The size of the voltage divider varies with the number of tubes used in the receiver. Generally the resistance is about 15,000 to 25,000 ohms. The resistance wire must also be heavy enough to stand the current that flows through it without burning out. The amount of current a resistor can safely pass at a given voltage is expressed by its rating in *watts*. A *watt* is a unit of electrical power measured by the product of the current and the voltage (pressure). Hence with a given voltage, as the current increases the rated number of watts must increase. It follows that the more current needed for the plate currents in the radio receiver, the heavier this resistor must be. In the present case, with an assumed pressure of 300 volts, the resistor must be rated at about 25 watts.

123. The Dropping Resistor

There is another way by which we can get the lower voltage needed for the plate of the detector tube. Instead of connecting the positive output terminal directly to the B terminal of the audio-frequency transformer in the plate circuit of the detector tube, we insert a resistor of about 5,000 ohms between the two points (see Figure 104). This plan involves the same principle of drop or fall in potential, because some of the electrical pressure is used up in forcing current through this resistor. As a result, a smaller positive charge is placed on the plate of the detector tube. This resistor is called a *dropping resistor*.

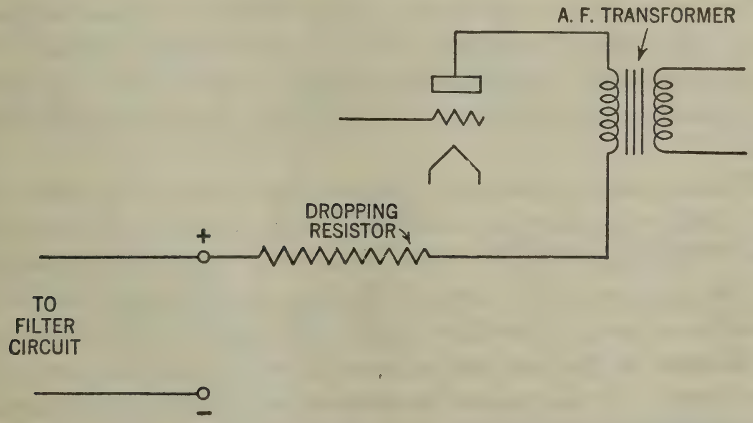


Figure 104. Circuit showing use of a dropping resistor to obtain the lower B voltage required for the plate of the detector tube.

Here, now, in Figure 105, is the plan for our completed *B-battery eliminator.*

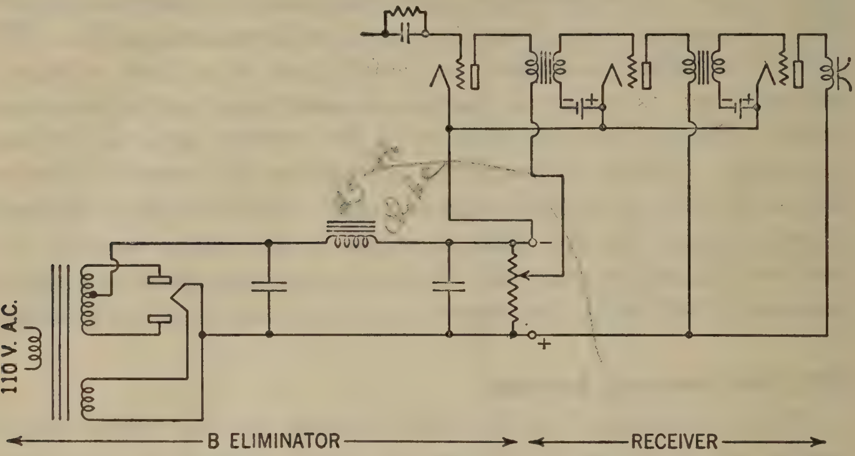


Figure 105. Completed B eliminator, showing how it is connected to the radio receiver. See if you can name each part and state its function. Where is the aerial-ground system connected?

124. How the B Eliminator Works

The primary of the power transformer is connected to the house line which supplies 110-volt alternating current. The step-up secondary increases this voltage to 300 volts. The ends of this secondary are connected to the plates of the type 80 rectifier tube.

The step-down secondary reduces the voltage to 5 volts. The ends of this secondary are connected to the filament of the rectifier tube. The negative line of the B-battery eliminator comes from the mid-point or *center tap* of the step-up secondary and is connected to one end of the filter input. The positive line comes from the filament of the rectifier tube and goes to the other end of the filter input. At this point the current is pulsating direct current at about 300 volts.

When this current passes through the filter it comes out as a steady direct current at about 300 volts. It makes no difference whether the choke coil is in the positive or negative line. In circuit diagrams it is usually shown in the positive line.

Across the negative and positive terminals of the B-battery eliminator the electrical pressure is 300 volts. The negative terminal is connected to the filaments of the tubes in the radio receiver, just as is the negative post of the B batteries when there is no eliminator. Similarly, the positive terminal of the eliminator is connected to the B+ terminal of the second audio-frequency transformer and the loudspeaker.

Across the terminals of the eliminator, a potentiometer is connected. The sliding tap is adjusted to a point where the electrical pressure or voltage is of the desired value, about 100 volts. A connection is made from this sliding tap to the B+ terminal of the first audio-frequency transformer.

125. Electrolytic Condensers

The condensers used in the filter circuit are very large, about 8 μfd. each. For this purpose we generally use condensers whose plates are made of tinfoil and whose dielectric is waxed paper. Recently, we have been using *electrolytic condensers.* These condensers have plates of aluminum and an aluminum oxide dielectric. In using these electrolytic condensers, care must be taken that the terminal marked POSITIVE or + is connected to the positive line and the terminal marked NEGATIVE or — is connected to the negative line of the filter circuit. Failure to observe this precaution may destroy the condenser.

The condensers used in the filter circuit are called *filter condensers.* Care must be taken that the dielectric is strong enough to withstand the electrical pressure—in this instance, at least 300 volts. This rating is usually marked on the side of the condenser.

SUMMARY

1. Batteries became such a nuisance in radio sets that means were sought to eliminate them.

2. The ordinary current delivered to the home is alternating current of 60 cycles at a pressure of 110 volts.

3. By passing the alternating current through a diode tube the current is rectified to pulsating direct current.

4. By the use of coils having high resistance, called choke coils, together with condensers, the pulsating current is changed to steady current. This system of chokes and condensers is called a **filter system.**

5. **Full-wave rectifying tubes** (type 80) are made with one filament and two plates. This design makes use of the half cycle of alternating current that is blocked off during rectification by a single diode.

6. **Potentiometers** are variable resistors by the use of which a high voltage may be reduced to any desired voltage through the principle that *drop* in pressure is proportional to resistance overcome.

7. The B-battery eliminator consists of a type 80 tube with resistors and filters so connected that all the functions of the dry-cell B battery are performed by energy from house alternating current.

GLOSSARY

B-battery Eliminator: A device used to eliminate the need for B batteries by supplying plate voltage from the house mains.

Dropping Resistor: A resistor connected in a circuit which uses up a part of the electrical pressure, thus leaving less voltage for the remainder of the circuit.

Electrolytic Condenser: A fixed condenser of high capacity with aluminum plates and a dielectric of aluminum oxide.

Filament Transformer: A step-down transformer used to supply filament current from the house mains.

Filter: An electrical network used to smooth out, or eliminate variations from, a pulsating direct current, thus changing it to a steady direct current.

Filter Choke: A coil of many turns wound on an iron core, used in a filter.

Filter Condenser: A fixed condenser of high capacity, used in a filter.

Full-wave Rectification: Rectification which uses both halves of the alternating-current cycle.

Half-wave Rectification: Rectification which uses only one half of the alternating-current cycle.

Power Transformer: A transformer used to step up the 110-volt alternating current from the house mains to a higher voltage. It may have several step-down secondaries, which are used to supply current to heat the filaments of the tubes.

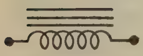
Rectified Current: An alternating current that has been changed to direct current by a rectifier tube or other rectifier device.

Rectifier Tube: A tube whose sole function is that of changing alternating current to direct current.

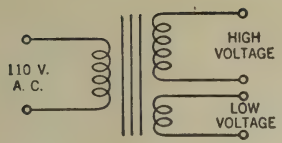
Voltage Divider: A resistor, placed across the output of the filter system, from which we may obtain various voltages by tapping off at points along its length.

Watt: The unit for measuring electrical power.

SYMBOLS



Filter choke.



Power transformer.

EXERCISES

1. Why is it normally desirable to eliminate batteries from a receiver?

2. What is the voltage and the number of cycles of the most common house current?

3. Why cannot normal alternating current be used in the radio receiver?

4. Show how a diode can act as a rectifier. Graph the resulting voltage.

5. What type of voltage emerges from a diode rectifier?

6. By what means is a rectified alternating current changed so that it can be used in our receiver?

7. Explain the operation of an electrical filter system.

8. Explain the operation of a half-wave rectifier.

9. Explain the operation of a full-wave rectifier.

10. Why is it easier to filter the output of a full-wave rectifier than it is that of a half-wave rectifier?

11. How may we secure various voltage levels from our power supply? Explain in detail.

12. What rating of a resistor expresses the amount of current that the resistor can safely pass without burning out?

13. Draw the circuit for a complete full-wave B-battery eliminator or power supply.

14. What care must be taken in using electrolytic condensers in the filter system of B-battery eliminators?

15. In using condensers, what must we consider in addition to the capacity rating?

CHAPTER 19

Eliminating the A Battery

Problem: *What device made it possible to use alternating current to heat the filament without distortion of the radio signals in the plate circuit?*

126. Attempts to Use Alternating Current for the Filament

The next battery to be eliminated was the A or filament battery. It is simple enough to use a step-down filament transformer to reduce the voltage from the 110 volts alternating current to 6 volts alternating current. But alternating current is unsatisfactory for heating the filament of the radio tube even at this reduced voltage.

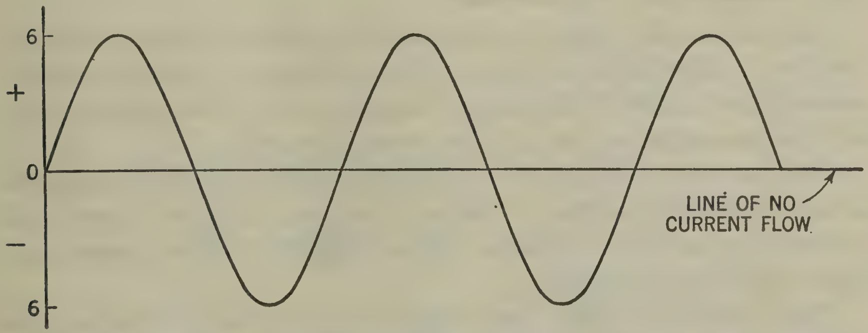


Figure 106. Wave form of alternating current used to heat the filament of the tube.

The reason is that any fluctuations in the stream of electrons shot out by the heated filament causes a hum or distortion of the signal. The plate current is the current produced by the stream of electrons from the filament to the plate. Examine the wave-form picture of the alternating current used to heat the filament in Figure 106.

When the alternating-current cycle reaches its peak (whether the positive or negative peak makes no difference here), the electrons are streaming through the filament at their maximum rate and the filament is being heated to maximum temperature. The electrons being emitted by the heated filament are shooting out at the maximum rate. When the alternating-current cycle reaches the line of no current flow, however, the filament starts to cool off and the number of electrons emitted starts to drop off. The result is a fluctuation in the number of the electrons reaching the plate, with resulting distortion of the signal.

127. First Experiments with Ribbons

One method that has been used to combat this undesirable condition was to make the mass of the filament greater. Instead of using a thin wire, a ribbon type of filament was used. Because of its greater mass, the temperature in such a filament does not fluctuate as much as in the thinner ones during the changes in the alternating-current cycle.

But the ribbon filament was not wholly successful for two reasons: (1) some fluctuations still remained, (2) to heat this massive filament required great amounts of electric current.

128. Attempts to Use Rectifiers

Another method used to overcome the difficulty was to convert the 6-volt alternating current to direct current, using a rectifier consisting of plates of copper and copper oxide. The action of this rectifier is similar to that of the crystal detector.

Still another method of rectifying the alternating current was to use a chemical rectifier. Plates of lead and aluminum were suspended in a solution of borax. This chemical rectifier passes current only in one direction.

The diode tube also was used as a rectifier, following the method described in the previous chapter.

All these methods of rectification were not very practical. They required special apparatus for the rectification and filter systems. The chemical rectifier had the additional drawback of being spilled easily.

129. Further Attempts to Use Alternating Current for Heating

The use of alternating current directly on the filament of the radio tube was tried in a number of ways, but one difficulty always

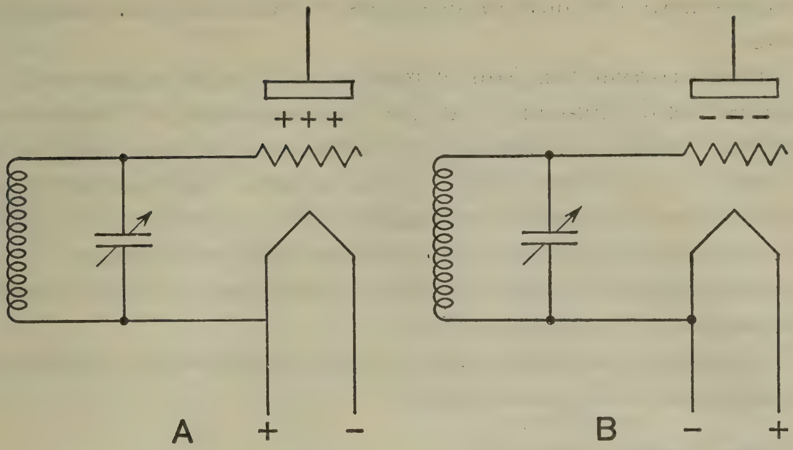


Figure 107. Circuits showing how alternating current flowing through the filament places an alternating charge on the grid of the tube.

remained. The grid of the tube, as you know, must be connected to the filament as shown in Figure 107. So if alternating current is sent through the filament, then during one half of the cycle a positive charge is placed on the grid as in Figure 107-A. During

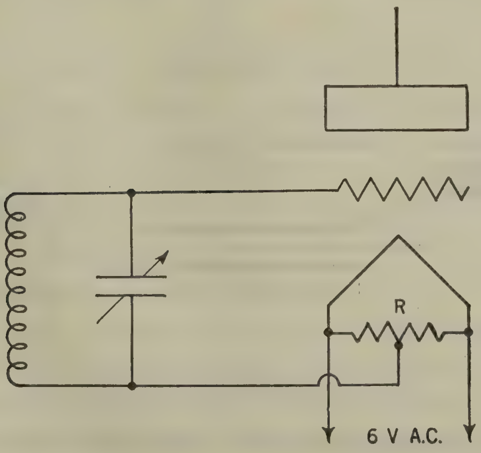


Figure 108. Circuit showing the use of a 20- to 40-ohm center-tapped resister (R) to reduce hum.

the next half of the cycle a negative charge is placed on the grid (Figure 107-B). Thus an alternating charge is placed on the grid by the alternating current flowing in the filament. This charge interferes with the flow of electrons to the plate and distortion results.

To help correct this fault a resistor of 20 to 40 ohms was connected across the filament. At the electrical center of this resistor, a tap was placed. To this tap was connected the wire going to the grid circuit (see Figure 108). It can be seen that whichever side of the filament is positive or negative, the center tap, being halfway between them, is always at the same electrical pressure. Thus a constant charge is placed on the grid and there are no unwanted fluctuations in the plate current.

This scheme, together with the use of the heavy ribbon-type filament, gave fairly good results.

130. The Cathode Sleeve

But a better method, permitting the use of alternating current on the filament, was subsequently worked out. Around the filament, but not touching it, was slipped a sleeve of metal. Now the filament was used as a stove to heat this sleeve. As the sleeve became hot, it emitted the stream of electrons which reached the plate.

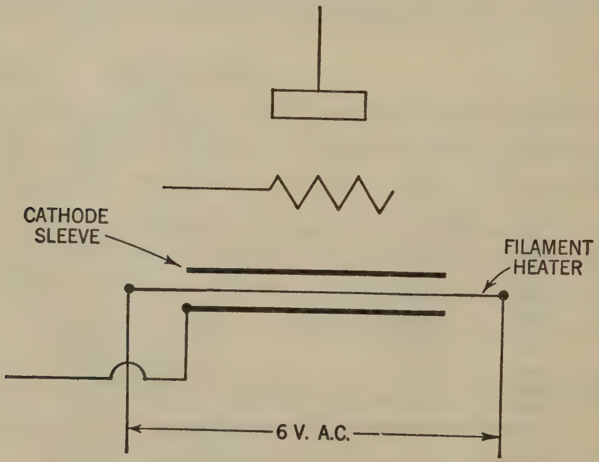
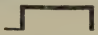


Figure 109. Diagram of tube with a cathode sleeve used as an emitter of electrons.

This sleeve is now the surface which gives off the electrons and is therefore called the *cathode*. Because it is quite massive, the temperature of the cathode does not change with the alternating-current cycle of the current flowing through the filament. Thus the stream of electrons it emits is steady. The symbol for the cathode is: 

The wire going to the grid, called the *grid return,* is connected to the cathode instead of to the filament. The filament is thus removed from the circuit bearing the radio signals. Hence the current used to heat the filament may be either alternating or direct current without causing distortion of signals.

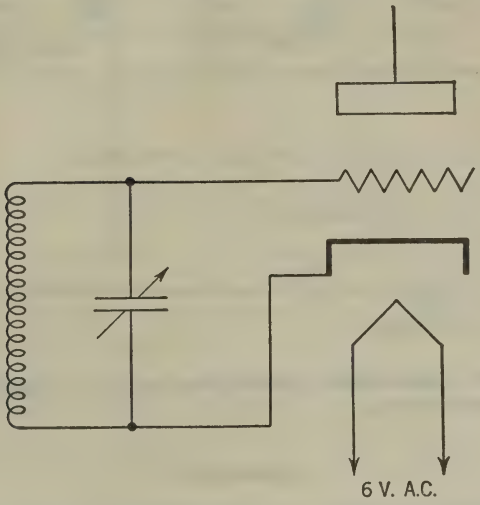


Figure 110. Circuit showing how the cathode is connected to the grid return.

In modern tubes the cathode is usually coated with special chemicals that make it a more efficient emitter of electrons. We shall discuss this matter more fully later.

131. The Complete A-battery Eliminator

The use of the cathode simplifies things a great deal. The only extra piece of apparatus for this new type of tube is the step-down filament transformer. An example of a tube using this cathode is the type 27.

We have now eliminated the need for the A or filament battery. A typical hookup using the cathode-type tube is shown in Figure 111. In studying this wiring diagram you should notice that the B— terminal of the B-battery eliminator is now connected to the cathode instead of the filament. Notice, also, that a third secondary winding has been added to the power transformer. This is a step-down secondary giving the 2½ volts needed for the filament of the type 27 tube.

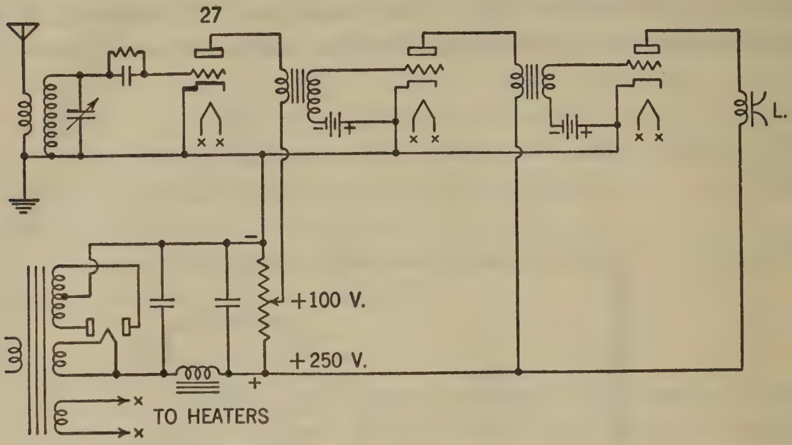


Figure 111. Radio circuit showing the use of a B-battery eliminator and cathode-type tubes.

SUMMARY

1. The alternating current is unsatisfactory for heating the filaments of radio tubes because of the uneven flow of electrons to the plate.

2. Various means of correcting the faults of the alternating current as a substitute for the A battery were tried before a successful method was found.

3. The device which was successful is the **cathode sleeve.** The principle in this is that the filament bearing the alternating current does not touch the cathode but merely heats it because it is close to it. The cathode therefore emits the electrons used in the plate circuit to carry the radio signals.

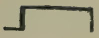
4. The type 27 tube has this cathode sleeve and needs to be operated at 2½ volts alternating current furnished by a step-down transformer.

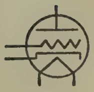
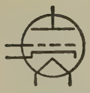
GLOSSARY

A-battery Eliminator: A device used to serve the purpose of the A battery by supplying the current needed to heat the filament of the tube from the house mains.

Cathode: A metal sleeve surrounding the filament in a tube and coated with chemicals that shoot off electrons when heated by the filament.

SYMBOLS

 Cathode in a tube.

 OR  A triode employing a cathode.

QUESTIONS AND PROBLEMS

1. What action results when alternating current is fed to the filaments of a tube?

2. What early attempt was made to overcome the effect of the alternating current in question 1?

3. List several methods other than that in question 2 to overcome the effect considered in question 1.

4. Explain how the use of a center-tapped filament resistor helps to stabilize grid voltage when an alternating current is fed to the filament.

5. What are the advantages of the type 27 tube?

6. If we are using tubes with cathodes, in what circuit is alternating current used?

7. Describe the chief features of the A-battery eliminator; make a diagram.

CHAPTER 20

Eliminating the C Battery

Problem: *How is the grid bias maintained without a C battery?*

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132. Keeping the Grid Negatively Charged

Having succeeded in eliminating the A and B batteries, radio engineers next tried to get rid of the C battery. It proved to be a simple matter to do away with this battery. Let us recall the function of the C battery.

Figure 112 shows the C battery connected in the grid circuit of the triode. Since the C battery (or grid-bias battery) is connected with the negative post to the grid return and the positive post to the filament, the grid is more negative than the filament. So all we have to do is to work out a system that makes the grid slightly more negative than the filament and our C battery is eliminated.

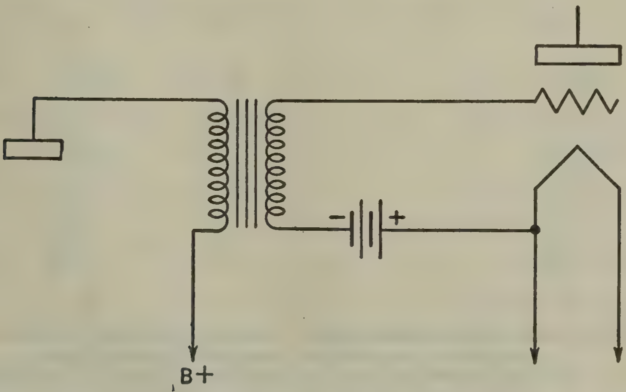


Figure 112. Circuit showing a C battery connected in the grid circuit of an amplifying tube. Why is this battery called a grid-bias battery?

133. Using a Voltage Divider

Turn back to Figure 105. The most negative point of the B eliminator is the negative terminal. Note that the filaments of the radio tubes are connected to that point. Now consider a point on the voltage divider a little distance away from the negative terminal and toward the positive terminal. As you now know, this point is a little more positive than the negative terminal.

Now, connect the filament to this new point and connect the grid return to the negative terminal. The grid in this hookup is slightly more negative than the filament and we have eliminated the necessity for a C battery.

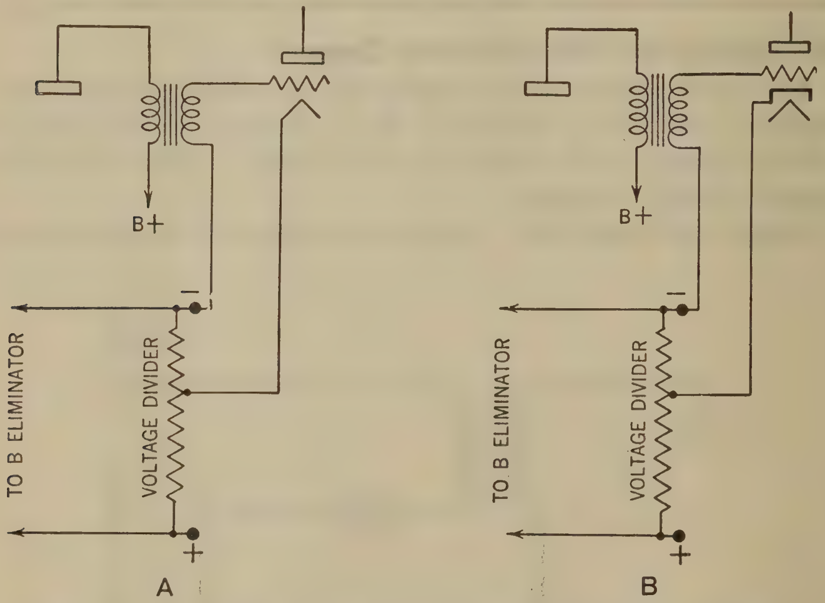


Figure 113. A—Circuit showing how a filament-type tube is connected to obtain the grid bias from the voltage divider.
B—Circuit showing how a cathode-type tube is connected to obtain the grid bias from the voltage divider.

Figure 113-B shows how a cathode-type tube is hooked up to eliminate the C battery.

134. Another C Eliminator

There are other methods used to eliminate the C battery. For example, it has already been stated that the most negative point of the B eliminator is the negative terminal. This means that the greatest excess of electrons has accumulated there. Hence when the grid return is connected to this terminal the grid, too, is negative.

The cathode, however, is not connected directly to the negative terminal of the B eliminator, but through a resistance of about 2,000 ohms, as in Figure 114. To understand this hookup, compare the pathways of electrons from the B-battery eliminator to the grid and to the cathode respectively. As the cathode shoots off electrons, other electrons are drawn up from the large supply on the negative terminal of the B eliminator. But some of the electrical pressure is lost in pushing these electrons through the 2,000-ohm resistor. In this hookup, then, the cathode is slightly less negative than the negative terminal of the B eliminator.

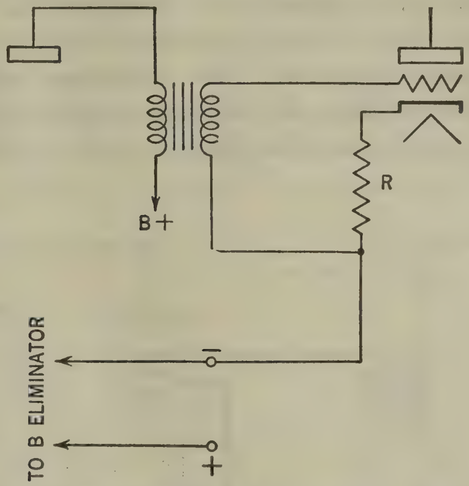


Figure 114. Circuit showing how a bias resistor (R) is used to obtain grid bias.

The grid of the tube, connected to this negative terminal without the resistor between it and the terminal, is therefore slightly more negative than the cathode. So now again there is no need for the C battery.

The resistor we connected to the cathode of the tube is called a *bias resistor*. Different types of tubes use different bias resistors. The 2,000-ohm resistor mentioned here is suitable for the type 27 tube.

135. Preventing Distortion with a By-pass Condenser

If you examine Figure 115, you will notice that this bias resistor is in the plate circuit. The electrons stream up from the negative terminal of the B eliminator, through the bias resistor to the cathode, across to the plate and through the winding of the loudspeaker and back to the positive terminal of the B eliminator. Since a fluctuating direct current is flowing in that plate circuit, this means that the difference in electrical pressure between the cathode and the grid will also fluctuate.

This condition is not desirable, for it reduces the amplification. To overcome this effect, a large condenser of about 1 μfd. is connected across the bias resistor. This condenser, called a *by-pass condenser,* smoothes out the fluctuations on the same principle as the filter condensers in the filter circuit of the B eliminator.

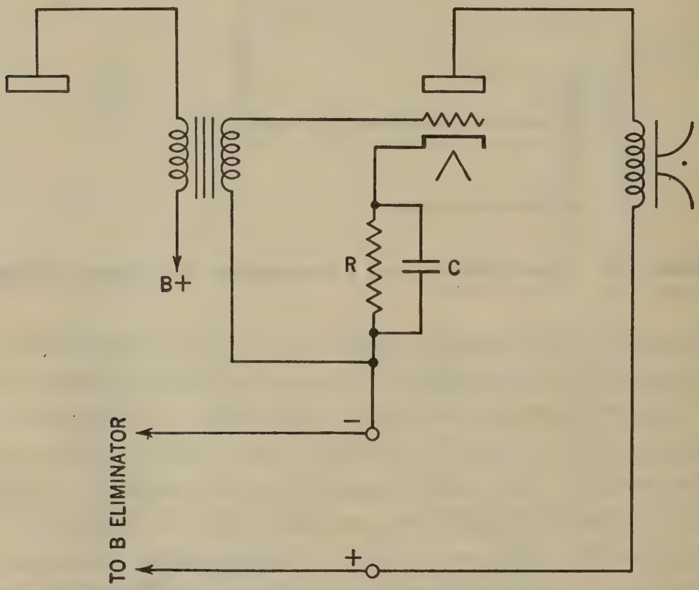


Figure 115. Circuit showing bias resistor (R) and by-pass condenser (C).

136. The Complete No-battery Receiver

Having succeeded in eliminating all batteries, we are now ready to present our no-battery radio receiving set. This is shown in Figure 116.

In this diagram, the wires connecting the filaments of the tubes to the step-down secondary, which gives the 2½ volts of alternating current needed to heat these filaments, are omitted for the sake of simplicity. In wiring this set, however, a certain precaution must be taken. These wires, carrying alternating current, have a fluctuating magnetic field around them. If this field cuts across any other conductor near them, currents will be induced which will interfere with the reception of the signal.

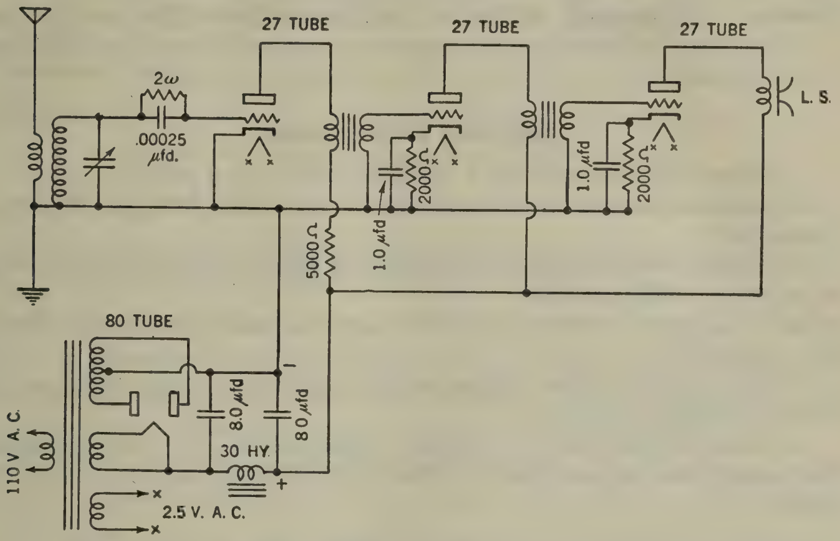


Figure 116. Diagram showing the circuit of an all-electric receiving set.

To overcome this unwanted effect, the wires carrying alternating current to the filaments are twisted around each other in such a way that the magnetic fields of these wires neutralize one another.

SUMMARY

1. To have the grid of a tube function properly it must have a small negative charge at all times.
2. The C battery which supplies a negative charge to the grid may be eliminated by properly connecting the grid to the B-battery eliminator.
3. Two methods of connecting the grid so as to obtain the suitable negative charge are: (a) to use a voltage divider; (b) to use a resistor in parallel with a by-pass condenser on the supply line to the cathode.
4. Wires bearing alternating current to the filament should be twisted together to neutralize the magnetic fields produced in single wires by the current.

GLOSSARY

By-pass Condenser: A fixed condenser placed across the cathode-bias resistor which serves to smooth out the current variations in that resistor and thereby supply the grid with a constant negative charge.

Cathode-bias Resistor: A resistor between the B— terminal and the cathode of the tube, which gives the grid a negative bias.

C-battery Eliminator: A device used to eliminate the need for the C battery by obtaining the necessary current from the B-battery eliminator.

QUESTIONS AND PROBLEMS

1. What is the purpose of a negative bias on the grid?

2. In what way can we obtain negative grid bias from the B-battery eliminator?

3. Explain the method of obtaining a negative grid bias by means of a cathode-bias resistor.

4. What is the purpose of the by-pass condenser across the cathode-bias resistor?

5. Why are the wires leading to the filament of a cathode-type tube usually twisted together?

6. Make a diagram of a receiver using an A-, B-, and C-battery eliminator, and an amplifier coupled by resistance coupling to the detector.

CHAPTER 21

The A.C.–D.C. Power Supply

Problem: *How are radio receivers adapted to operate on either alternating- or direct-current power supply?*

The battery eliminators described in the previous chapters all assume the use of 110-volt alternating current. In a number of localities, however, the house mains supply 110-volt direct current. Since a transformer will not operate on steady direct current, it becomes obvious that the A- and B-battery eliminators previously described will not work in these direct-current localities.

There are other reasons for not using the power transformer, even in alternating-current localities. The innovation of the midget receiving set has placed a premium upon small, light receivers that can be built cheaply. Since the power transformer is bulky, heavy, and expensive, its elimination was desired by the receiving-set manufacturers. Let us see how the problem was solved.

137. Current for the Filament and Amplifier

The answer is in our half-wave rectifier system (Figure 98). If we eliminate the step-up transformer and feed the 110-volt alternating current directly to the plate of the rectifier tube and filter system, we can change the house current to a steady direct current. True, we can only get about 110 volts output, but with the invention of the new and more efficient tubes, this voltage suffices for ordinary purposes.

Using this scheme and applying 110-volt direct current so that the positive lead goes to the plate of the rectifier tube, we get the same result as with the alternating current. So here we have a B-battery eliminator that works equally well on alternating or direct current and uses no power transformer.

138. Reducing the Voltage by Resistors Instead of Transformers

Now for the filament current. When the house mains supply 110-volt alternating current, we can get the small voltage required to heat the filaments by one of two methods. We can use a step-down transformer as described in Chapter 19. Or else we can force the 110-volt alternating current to go through a resistor before it goes through the filaments. When current goes through this resistor, its electrical pressure is reduced to (that is, *drops* to) the small amount necessary to force it through the filaments.

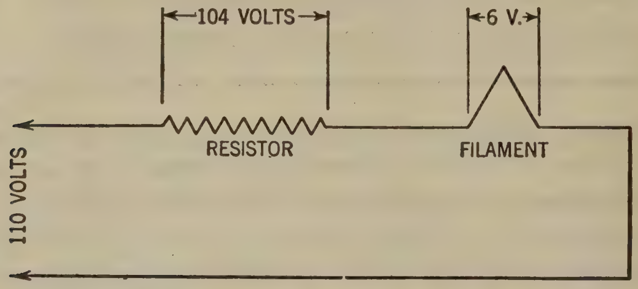


Figure 117. Diagram showing how a resistor is used to cut down the 110-volt house current to a value suitable for use on the filament of the tube.

This second method is not as desirable as the step-down transformer method, because it wastes most of the current going through the resistor. But in a direct-current locality only the resistor method of obtaining the filament current can be used. We therefore are compelled to use this method if the receiving set is to be operated in both types of localities.

139. Connect Filaments in Series

An increase in efficiency is gained if we connect our filaments in series. Assume that the rectifier tube requires 5 volts to force the current through its filament, while the detector tube, the first audio-frequency amplifier tube, and the second audio-frequency amplifier tube each require 6 volts.

When any electrical conductors are connected in series the resistance of the circuit is the sum of the resistances of all the parts. Hence 23 volts are required for the filaments of the tubes and only 87 volts are wasted in the resistance. (23 volts + 87 volts = 110 volts.)

Modern tubes are being manufactured that require even greater voltage for their filaments and when they are used there is still smaller waste. As a matter of fact, some tubes use 110 volts on their filaments. These tubes are connected in parallel across the 110-volt line and no resistor is needed.

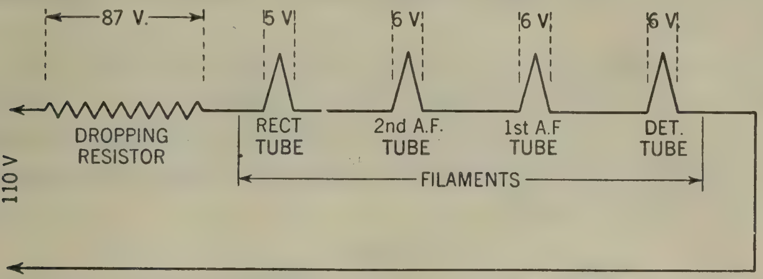


Figure 118. Diagram showing how the dropping resistor and the filaments of the rectifier, detector and first and second audio-frequency amplifier tubes are connected in series across the 110-volt house line.

140. Line-cord Resistor

The resistor used in these circuits is called a *dropping resistor.* Its value obviously must vary with the type and number of tubes used. One variety of dropping resistor is the *line-cord resistor.* This resembles a common two-wire extension cord attached to a plug of the type used in the ordinary type of electrical outlet. But in addition to the two wires of this electric cord and attached to one of the terminals of the plug is a wire resistor of the proper size. The voltage drop in these resistors is made to provide for the correct voltage in the filament.

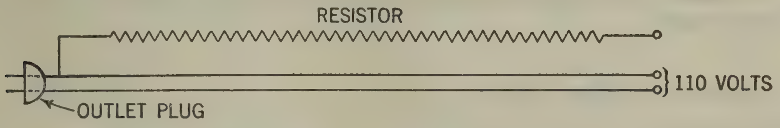


Figure 119. Diagram showing a line cord with a built-in resistor. The electric cord and resistor are covered with an asbestos and cotton casing and the assembly looks very much like the electric cord used to connect an electric iron.

This arrangement furnishes a convenient method for attaching the set to the house current and gives the additional advantage of having the resistor outside the set. Since the dropping resistor heats up somewhat because of the resistance to the current passing through it, it is advantageous to have it outside the set. Needless to say, you must not shorten or cut this cord or else you will reduce the value of the dropping resistor.

141. Other Features of A.C.–D.C. Sets

The C battery is eliminated as described in Chapter 20. Since the grid bias must be negative and not variable, the proper bias can be obtained by using proper resistors with any direct-current power supply.

It is possible, then, to wire a receiving set so that the plug supplying the electrical energy for all purposes may be used in any outlet for the house current regardless of whether the supply is alternating or direct current. Figure 120 shows the complete A.C.–D.C. power supply.

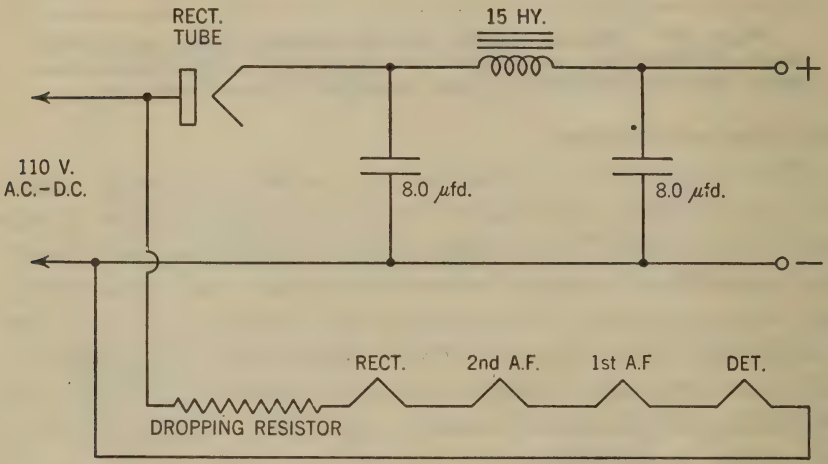


Figure 120. Diagram showing the circuit of the complete A.C-D.C. power supply.

142. Better Rectifier Tubes

Practically any radio tube can be used as a rectifier. Some tubes, however, like the type 25Z5, are more efficient for this purpose.

143. One Precaution

If a receiving set fails to work in a direct-current locality when the set is plugged into the electrical outlet, remove the plug from the outlet, reverse it, and plug it in again. The chances are that you have plugged it in so that the negative line is connected to the plate of the rectifier tube. Reversing the plug will remedy this.

SUMMARY

1. B-battery eliminators made to operate by the use of step-up and step-down transformers cannot be used on direct-current house mains.

2. The principle involved in the modern A.C.–D.C. receivers is to use resistors instead of transformers to produce lower voltages and to use smaller tubes of new types.

3. A.C.–D.C. sets operate by plugging in to any outlet carrying commercial current. The extension cord usually contains a line-cord resistor to provide the correct voltage for the filaments.

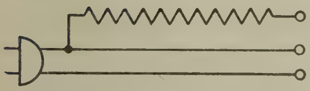
4. On direct-current circuits it is sometimes necessary to turn a plug around in the outlet fixture so that the direct current may enter the right wire.

GLOSSARY

A.C.–D.C. Power Supply: A battery eliminator that operates from 110-volt alternating or direct current.

Line-cord Resistor: A resistor in the power line which uses up most of the 110 volts, leaving a small portion for the filaments.

SYMBOLS



Line-cord resistor.

QUESTIONS AND PROBLEMS

1. Why must we use a special power supply where direct current is furnished?

2. What is the approximate voltage output of an A.C.–D.C. power supply into which we feed 110-volt alternating or direct current?

3. How are filament voltages obtained in an A.C.–D.C. power supply?

4. What name is given to a resistor in the power cord of an A.C.–D.C. receiver?

5. What danger is there in cutting the power cord of an A.C.–D.C. receiver to make it shorter and less cumbersome?

6. If a receiver with an A.C.–D.C. power supply fails to operate in a direct-current district, after being tested, what would you examine in hunting for a possible cause?

CHAPTER 22

The Dynamic Speaker

Problem: *How has the loudspeaker been improved so as to give greater volume without distortion?*

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144. Faults of the Paper Cone Speaker

Turn back to Figure 19. Although we have greatly improved our radio receiver since we built the crystal detector set, our loudspeaker has remained a paper cone fastened to the diaphragm of the earphone. Now let us give it some attention.

The loudspeaker, as shown, has one very bad fault. Our amplified signal is carried by a large current. This current from the plate circuit of the last amplifier tube passes through the coil of the speaker. When the resulting strong pull is exerted on the diaphragm, it is bent back until it touches the end of the permanent magnet. The effect is that the speaker rattles on loud signals.

145. The Permanent-magnet Dynamic Speaker

An ingenious device was evolved to overcome this defect. A speaker coil, called a *voice coil,* was wound on a small tube of bakelite. This tube was mounted so that it could slide back and forth on the permanent magnet. To this tube, the paper cone was attached. Also attached to this tube, to keep it in place, was a thin, springy sheet of bakelite called a *spider.*

The permanent magnet appearing in Figure 121 has a magnetic field around it. The fluctuating plate current, flowing through the voice coil, sets up a second, fluctuating magnetic field around the coil. These two magnetic fields, reacting with each other, move the voice coil up and down the permanent magnet. The greater the current flowing through the voice coil, the more this coil is moved down the permanent magnet.

The thin, springy spider permits the voice coil to move, but forces it to come back once the pull ceases. The paper cone, connected to the voice coil, moves with it.

Now, large plate currents can move the paper cone quite vigorously without the danger of a diaphragm striking the end of the magnet and thus causing rattling.

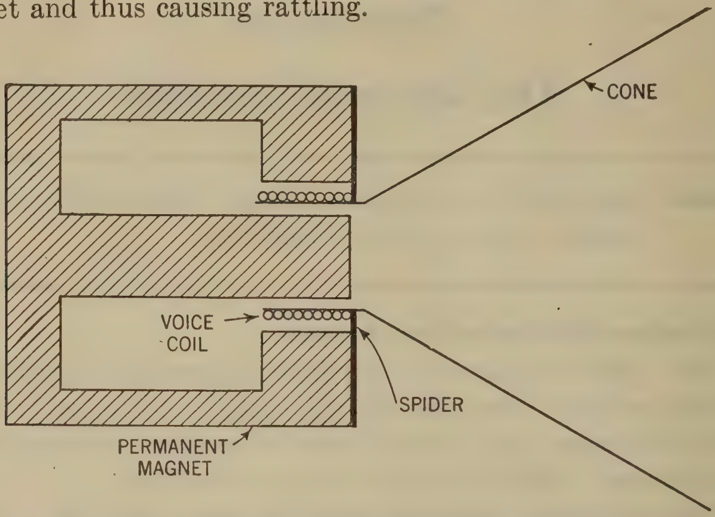
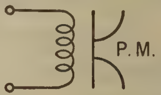


Figure 121. Diagram of a permanent-magnet dynamic speaker.

Of necessity, the voice coil, and the tube upon which it is wound, must be very light. The coil consists of a few turns of fine copper wire and the tube is made of very thin bakelite.

This type of speaker is called a *dynamic speaker*. Since it has a permanent magnet, we call it a *permanent-magnet dynamic speaker*. The symbol for this type of speaker is: 

146. The Output Transformer

There are two reasons why the voice coil cannot be connected directly in the plate circuit of the last amplifier tube. First of all, since the wire of the coil is very fine, the heavy plate current would burn it out. Secondly, it has been found that the most efficient transfer of power takes place when the resistance of the voice coil equals the resistance of the amplifier tube (Chap. 38, Vol. II).

The tube resistance is quite high, about 9,000 ohms for the type 27 tube. But since the voice coil must be kept light, it is wound with a few turns of wire and its resistance usually is from 2 to 30 ohms.

Here our old friend the step-down transformer comes to the rescue. The primary, which is connected in the plate circuit, has a great many turns and its resistance equals the tube resistance, thus insuring the maximum transfer of power. The secondary has few turns and its resistance is made to equal the resistance of the voice coil, thus again insuring the maximum power transfer.

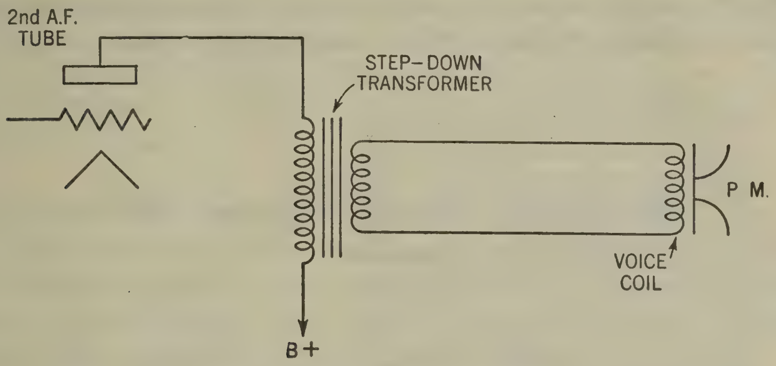


Figure 122. Diagram showing how a step-down transformer (output transformer) is used to couple the voice coil of the permanent-magnet dynamic speaker to the plate circuit of the second audio-frequency tube.

In Figure 122 you can see that in this hookup the heavy plate current does not flow through the voice coil and thus the danger of burning it up is removed.

The step-down transformer, used in connection with the dynamic speaker, is called an *output transformer.* Since different tubes have different resistances and the voice coils of different speakers, too, may have different resistances, an output transformer of different design must be used to match each new combination of amplifier-tube and voice-coil resistance.

147. Electromagnetic Dynamic Speaker

The permanent-magnet dynamic speaker still has several drawbacks. The permanent magnet deteriorates in time and the speaker gradually gets weaker. This fault may be partly remedied by the use of such alloys as Alnico, which make better, longer-lasting permanent magnets.

A more serious fault in the permanent-magnet speaker is the fact that where very loud sound is desired, as for auditorium or outdoor use, the permanent magnet cannot create a magnetic field great enough to move the paper cone properly.

To overcome these difficulties, a variation of the dynamic speaker is made which has an electromagnet replacing the permanent magnet. This electromagnet, called the *field coil,* is connected to a source of steady direct current. Since the field coil consists of a great many turns of wire, we now have a constant, powerful magnet which sets up a strong magnetic field as long as the current flowing through it is steady and constant. This field coil is wound around a soft-iron rod upon which the voice coil slides.

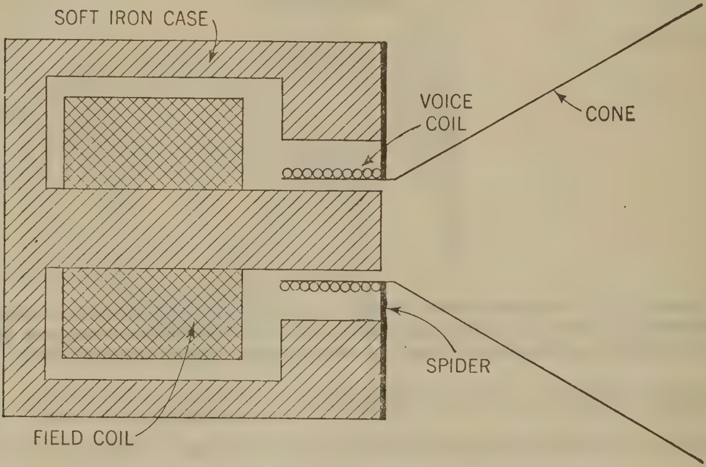
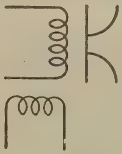


Figure 123. Diagram of an electromagnetic dynamic speaker. The field coil replaces the permanent magnet of the P. M. dynamic speaker.

This type of dynamic speaker is called an *electromagnetic dynamic speaker.* As in the case of the permanent-magnet dynamic speaker, electrical energy is transferred from the plate circuit of the last amplifier tube to the voice coil by means of an output transformer. The symbol for the electromagnetic dynamic speaker is: 

148. Supplying Current for the Field Coil

There are several means for obtaining the steady direct current needed for the field coil of this speaker. We may use a separate storage battery of 6 or 12 volts for this purpose. The field coil must be designed to operate on this low voltage. The use of storage batteries is a nuisance, but this method is used for special purposes, such as operating a loudspeaker in a moving automobile.

149. Separate Filter System for the Speaker

Another method without a battery is to use a separate rectifier and filter circuit for the speaker. The systems described in Chapter 18 and Chapter 21 can be used. For these systems we must design the field coil to operate on the higher voltages obtained. This method of obtaining a field-coil current supply is used chiefly for auditorium or outdoor purposes where very loud sound is desired.

150. Using Power from the B Eliminator for the Speaker

The method that is most commonly used for supplying current to the field coil without the use of batteries, is to pass the steady direct current flowing out of the B eliminator through the field coil before it is passed on to the radio receiver.

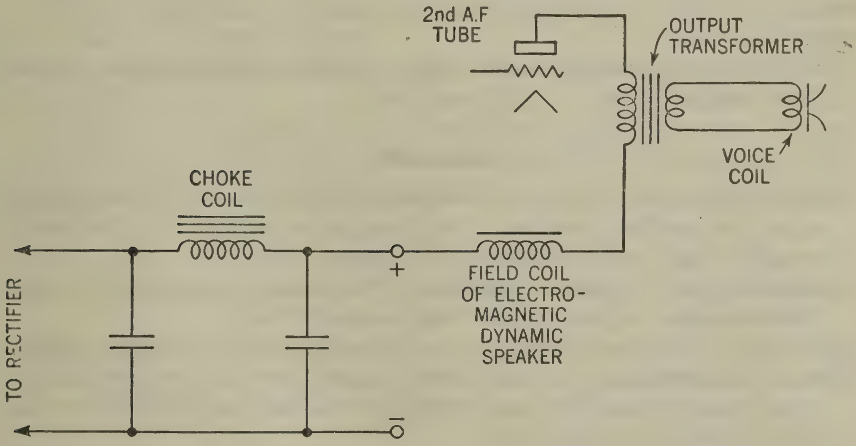


Figure 124. Diagram showing how current is obtained from the power supply to operate the field coil of the electromagnetic dynamic speaker.

Not only does this system eliminate the need for a separate storage battery or power supply for the speaker, but the field coil acts as a second choke coil and thus helps further to filter the plate current supplied to the radio receiver.

The electromagnetic dynamic speaker is widely used in sets that remain permanently near a source of house current. In portable receivers, however, to avoid the necessity for using a separate battery to energize the field coil, permanent-magnet dynamic speakers are usually used.

SUMMARY

Complete the meaning of the following statements by supplying the missing words. *Do not write in the book!*

1. The loudspeaker is an adaptation of that part of a telephone system called the (1) . The part which transmits the energy to the air is called the (2) , and sound reaches the ears by means of sound (3) through the (4) .

2. The first type of loudspeaker used a (5) cone attached to the (6) by means of a (7) . The louder sound was produced because the (8) (9) set more air in motion than did a metal diaphragm alone.

3. There are two types of dynamic speakers called the (10) (11) and the (12) (13) .

4. When magnetism is produced in the speaker by electricity the current must be (14) (D.C. or A.C.) .

5. The chief principle of a dynamic speaker is that a moving coil called a (15) responds to varying magnetic (16) set up by the (17) current from the second (18) (19) amplifying tube.

6. To provide current for the field coil of an electrodynamic speaker the best method is to (20; explain) .

GLOSSARY

Dynamic Speaker: A type of loudspeaker that depends for its operation upon the reaction between a fixed magnetic field and the fluctuating magnetic field produced around the voice coil.

Electromagnetic Dynamic Speaker: A dynamic speaker that uses an electromagnet to produce the fixed magnetic field.

Field Coil: The electromagnet of an electromagnetic dynamic speaker.

Output Transformer: A step-down transformer that couples the electrical energy from the plate circuit of the last audio-frequency amplifier tube to the voice coil.

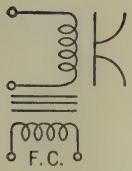
Permanent Magnet: A magnet that retains its magnetism after the magnetizing force which produced it is removed.

Permanent-magnet Dynamic Speaker: A dynamic speaker that uses a permanent magnet to produce the fixed magnetic field.

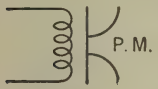
Spider: A piece of elastic material that constantly tends to return the voice coil to its normal position.

Voice Coil: The small coil of the dynamic speaker through which electrical energy from the plate circuit of the last audio-frequency amplifier tube is fed, setting up a fluctuating magnetic field that reacts with the fixed magnetic field to drive a cone, thus producing sound.

SYMBOLS



Electromagnetic dynamic speaker.



Permanent-magnet dynamic speaker.

QUESTIONS AND PROBLEMS

1. What was one defect of the diaphragm type of loudspeaker?
2. What current provides the energy for the voice coil of a loudspeaker?
3. What causes the voice coil of a loudspeaker to move?
4. Describe the structure of a permanent-magnet dynamic speaker.
5. Why cannot the voice coil be connected directly in the plate circuit of the last amplifier tube?
6. By what means is the voice coil of a loudspeaker coupled to the last amplifier tube?
7. What are some faults of a permanent-magnet dynamic speaker?
8. How is the field coil of an electromagnetic speaker energized (that is, given energy)? Describe two methods.

CHAPTER 23

The Radio-frequency Amplifier

Problem 1: *What is the purpose of the radio-frequency amplifier?*
Problem 2: *What are the parts of a tuned radio-frequency amplifier?*
Problem 3: *How are the faults of a tuned radio-frequency amplifier corrected?*
Problem 4: *How are radio- and audio-frequency amplifying systems connected in a five-tube receiving set?*

When future historians record the achievements of the first half of the twentieth century, the most outstanding accomplishment, perhaps, will be the conquest of time and space. The invention of the airplane destroyed distance. Oceans were spanned and continents crossed in a matter of a few hours.

But fast though the airplane is, it cannot compare with the speed of radio, which can flash the spoken word seven times around the world in one second!

151. More Power Needed

To utilize fully the magical powers of radio, the receiver must be made much more sensitive than the set we have just finished describing. True, the audio amplifier could build up the signal from a whisper in the earphones to a volume loud enough to fill a large auditorium; but in order to function, it had to receive this signal from the detector. The radio-frequency current in the aerial-ground system must be powerful enough to operate the detector.

Now a very powerful transmitting station, operating a few miles from the receiver, can set currents flowing in the aerial-ground system large enough to give satisfactory results. But weak stations, many miles away, are unable to emit a wave with sufficient energy to build up a signal that can be passed on to the audio amplifier.

The problem therefore is to devise a system that will build up the signal before it reaches the detector.

152. The Radio-frequency Amplifier

When radio development encountered this problem, the three-element radio tube once again was called on to act as an amplifier. In this case the current flowing into the amplifier alternates at a frequency of hundreds of thousands or even millions of cycles per second. It alternates, that is, at radio frequency. For this reason the amplifier is called a *radio-frequency amplifier* to distinguish it from the audio-frequency amplifier in whose circuit the current was alternating at audio frequency, that is, between 30 cycles and 15,000 cycles per second.

The radio-frequency amplifier works in the same way as does the audio-frequency amplifier. A small alternating voltage places an alternating charge upon the grid of the radio tube. This grid charge in turn controls the large plate current supplied by the B battery (see Chapter 17).

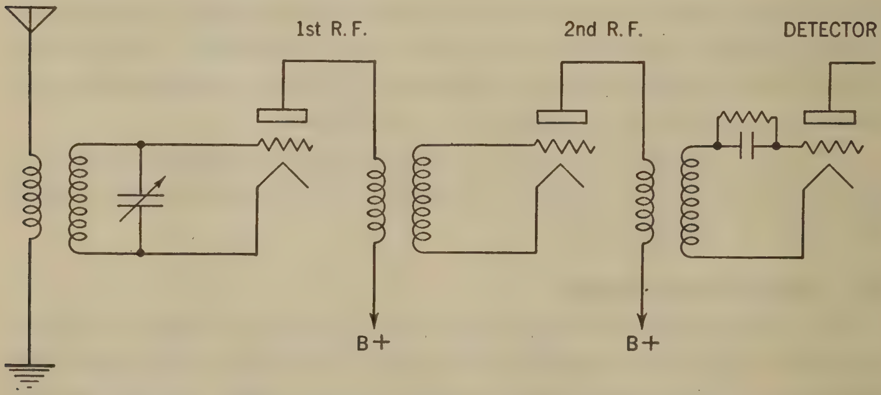


Figure 125. Diagram showing the circuit of two transformer-coupled radio-frequency amplifier stages. The "C" batteries are omitted here for the sake of simplicity.

The methods for coupling one radio-frequency amplifier tube to another are likewise the same methods used in the audio-frequency amplifier: either transformer or resistance coupling. But resistance coupling in radio-frequency amplifiers is seldom used and we need not discuss it here.

The method of coupling most commonly used is transformer coupling. The transformer used for radio-frequency amplification differs from the audio transformer in that it is usually an air-core transformer and has fewer turns. Like the audio transformer, it has a step-up winding that makes for a greater gain in signal strength.

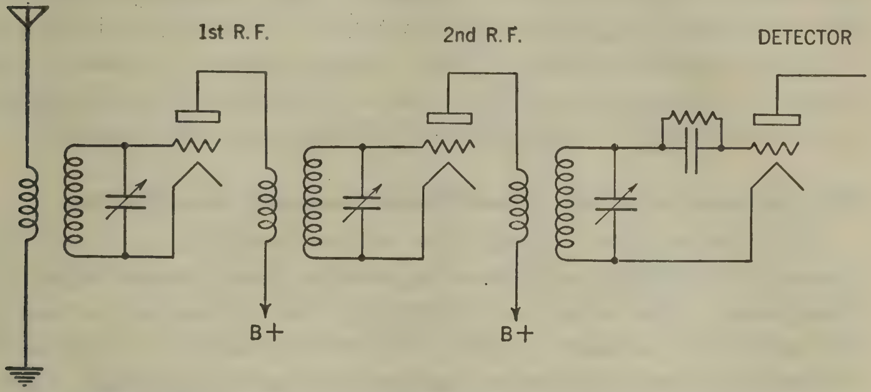


Figure 126. **Diagram showing the circuit of two tuned radio-frequency amplifier stages.**

153. The Tuned Radio-frequency Transformer

If you examine Figure 125, you will see that the radio-frequency transformer resembles the antenna coupler. The only difference is that the secondary winding of the antenna coupler is in a tuning or "tuned" circuit, while the secondary of the radio-frequency transformer is not. However, it was soon discovered that certain advantages could be gained if the secondary of the transformer

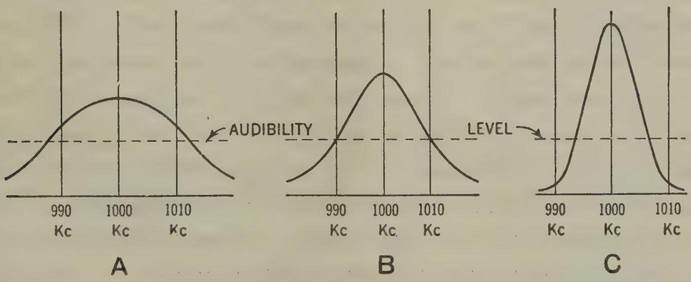


Figure 127. **A—Tuning curve with one tuned circuit. Notice that stations at 990 kc. and 1,010 kc. are heard when the set is tuned to 1,000 kc.**
B—Tuning curve with two tuned circuits. Note that the two unwanted stations are just at the audibility level.
C—Tuning curve with three tuned circuits. The two unwanted stations cannot be heard.

was made a part of a tuned circuit by connecting it with a variable condenser similar to the one used to tune the secondary of the antenna coupler.

You already have learned how the tuning circuit permits the signal from the station of the desired frequency to flow through it and tends to stop all others. However, some unwanted frequencies do manage to get through the tuner. If the signal is forced to pass through a series of such tuning circuits, however, the chances for the unwanted frequencies to leak through become proportionately less. In this way our set becomes more selective.

154. Advantages of the Tuned Radio-frequency Amplification

A radio-frequency transformer whose secondary is tuned by means of a variable condenser is called a *tuned radio-frequency transformer.* The tuned radio-frequency transformer is practically the same as the antenna coupler, while the variable condenser used for tuning is similar in size to that used in the tuning circuit. The secondaries of the transformers are all tuned to the same frequency as the secondary of the antenna coupler. A stage of radio-frequency amplification using a tuned radio-frequency transformer with a variable condenser is called a stage of *tuned radio-frequency amplification.*

When we use two stages of tuned radio-frequency amplification (Figure 126), we have three tuned circuits. Thus our set is much more selective than if we had only one tuned circuit (Figure 127).

Tuned radio-frequency amplification has another advantage over an untuned stage. Since the natural frequency of the tuned circuits is the same as the frequency of the incoming signal, the oscillations of the electrons in the tuned circuits are permitted to build up and this building up results in a louder signal. Of course, one disadvantage of the tuned stage is that it requires an additional variable condenser and an additional dial or knob accordingly must be manipulated.

155. Eliminating the Effect of Stray Magnetic Fields

One of the difficulties encountered in the manufacture of the radio-frequency amplifier is the fact that the magnetic field around one radio-frequency transformer may be large enough to cut across the coils of another such transformer. This action sets an unwanted current flowing in the second transformer and oscillations and distortion of the signal results. This evil is remedied in several ways.

Of course, we may space these transformers far enough apart to prevent this unwanted effect. But this plan is not practical, especially since we do not want our receiving set to be too large.

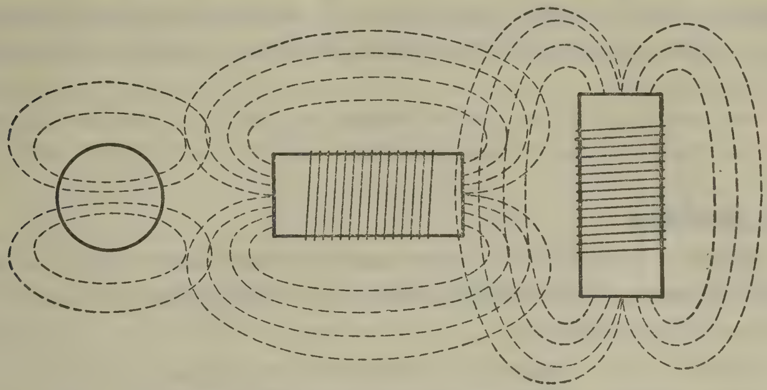


Figure 128. Tuned radio-frequency transformers mounted at right angles to each other. The dotted lines about each coil represent its magnetic field. Note that the transfer of electrical energy from one coil to the others is at minimum efficiency.

156. Setting the Transformers at Right Angles to Each Other

Another solution is to mount our transformers so that the windings, and hence the magnetic fields, are at right angles to each other. In such an arrangement, the transfer of energy from one

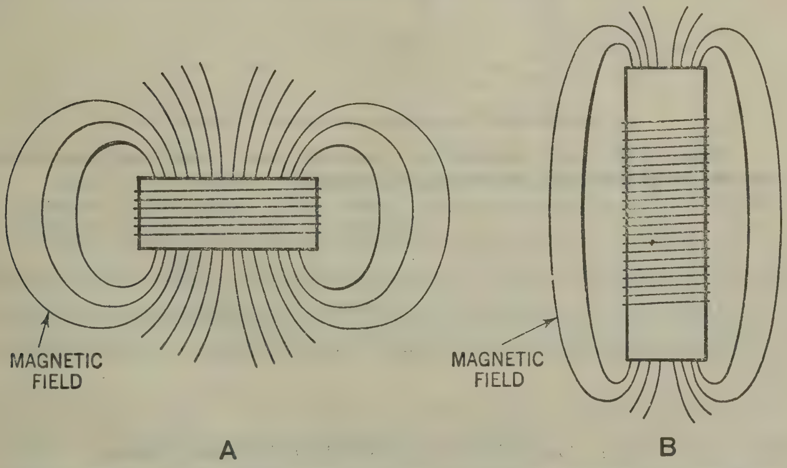


Figure 129. A—Magnetic field around a short coil of large diameter. Note how the field spreads out.
B—Magnetic field around a long coil of small diameter. Note that the magnetic field remains close to the coil.

transformer to another is at a minimum. (See the discussion of Coupling in the Regenerative Receiver in Paragraph 98.)

157. Coils with Smaller Diameters

Still another solution is to design our transformer so that its magnetic field is kept close to it. A short coil of large diameter has a wider magnetic field around it than a long coil of smaller diameter.

We now make our transformers an inch or less in diameter and use more turns of wire.

158. Shielding

Another solution is to surround the transformer with a metal shield or case. This shield absorbs the magnetic field and very little of it gets through.

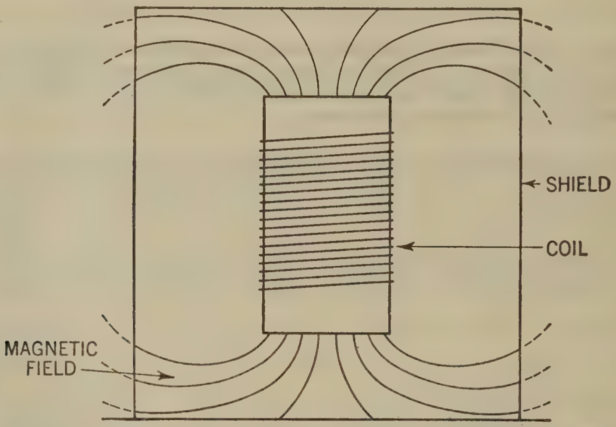


Figure 130. Coil shielded by a metallic can. Note that very little of the magnetic field penetrates the shield.

This method is called *shielding* and modern radio receivers use this device together with the narrower coil. The symbol signifying a shielded coil consists of a dotted line placed around this coil. The metals most commonly used for shielding are aluminum and copper.

Shielding is often used also to protect the radio-frequency amplifier tube from the effects of stray magnetic fields. Less frequently, the entire radio-frequency amplifier stage, consisting of the transformer, the variable condenser, the radio tube, and the wiring, is enclosed in a shielding case. Such complete shielding is rarely necessary. It usually suffices to shield the radio-frequency transformer and tube.

All metal used for shielding must be connected to the ground of the receiver.

Audio-frequency amplifiers are less subject to the effects of these stray magnetic fields. Nevertheless, the audio transformers are usually shielded and mounted so that the windings of one transformer are at right angles to the windings of the other.

159. The Elimination of the Feedback

In designing radio-frequency amplifiers, means must be taken to avoid feedback. In the regenerative detector circuit we deliberately caused some of the plate current to be fed back to the grid circuit (see Chapter 16). This feedback was carefully controlled and made the set more sensitive.

In the radio-frequency amplifier, however, such feedback is undesirable for it results in oscillation and other distortions of the signal. Such feedback may come from several sources and all of it must be eliminated.

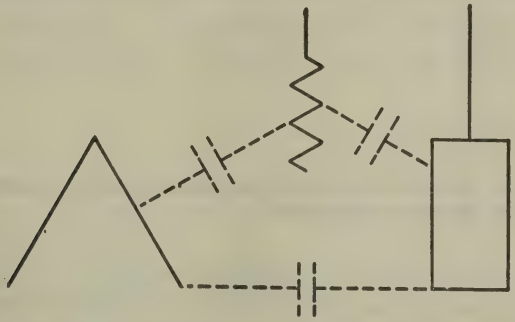


Figure 131. Diagram showing the capacity effect existing between the electrodes of the triode. The result is the same as if small condensers were connected between the electrodes.

The chief source of feedback lies in the tube itself. Any two conductors, separated by a dielectric, will form a condenser. The electrodes of the tube are such conductors. The dielectric is the vacuum between them.

160. How Capacitance Is Produced in Tubes

Thus a capacitance exists between the filament and the grid, the grid and the plate, and the filament and the plate. Because of the small area of the conductors, these condensers have small capacitance. But small though it is, the capacitance provided by the combination of the grid and the plate causes considerable trouble. By means of this small capacity effect, the output circuit (the plate circuit) and the input circuit (the grid circuit) are linked and feedback occurs.

Examine the circuit of the stage of radio-frequency amplification shown in Figure 132.

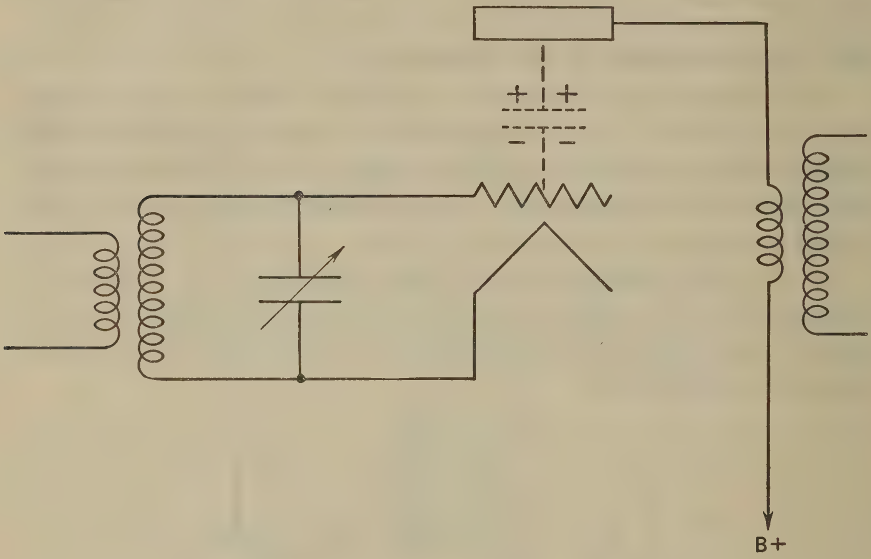


Figure 132. How the charge on the plate causes an opposite charge to be placed on the grid of the tube.

The B battery places a positive charge on the plate of the tube. Fluctuations of the plate current, resulting from the signal, will cause this positive charge on the plate to fluctuate.

Now consider the plate and grid as two conductors forming a condenser. The plate of the tube, being charged positively, causes a certain number of electrons to gather on the grid. The grid, that is, gets a negative charge. The more positively charged the plate, the more electrons are pulled over to the opposite electrode of the condenser, the grid.

The more highly positive the plate, then, the more electrons flow through the secondary of the radio-frequency transformer to the grid. As the plate loses some of its positive charge, some electrons are forced to flow from the grid back through the secondary of the radio-frequency transformer.

Thus the fluctuating charge on the plate of the tube sets up a corresponding oscillation of the electrons in the grid circuit. This oscillation causes distortion and must be eliminated.

161. Correcting the Influence of the Capacitance within the Tube

There are several methods of correcting for this tube capacitance. One is to connect a 500-1,000-ohm resistor in the grid circuit.

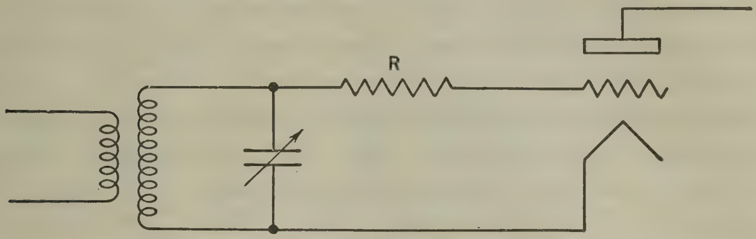


Figure 133. The "losser" method of preventing oscillations in the radio-frequency amplifier. The resistance R dissipates the unwanted flow of electrons.

This resistor uses up the electrical pressure of the electrons set oscillating in the grid circuit described above, and the distortion is therefore eliminated. This method of eliminating feedback is called the *losser method.* It suffers from the disadvantage that it dissipates not only the unwanted flow of electrons caused by feedback, but also some of the desired signal voltage. The result is a loss of amplification.

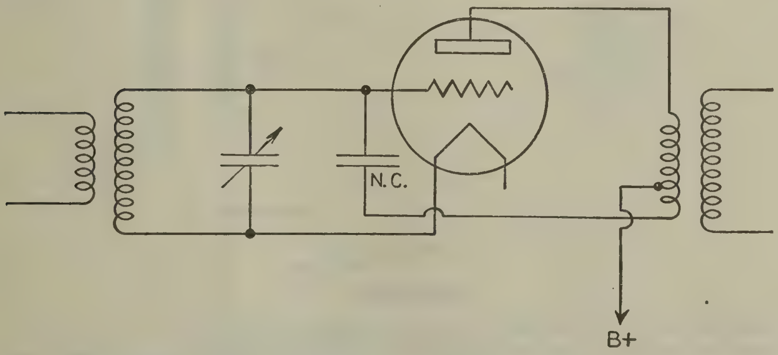


Figure 134. How a neutralizing condenser (N. C.) is employed to eliminate the feedback due to the internal capacitance between the grid and plate of the tube.

Another method for preventing feedback is the *neutralization method.* A small condenser, as shown in Figure 134, is connected across the grid and plate of the tube in such a way as to neutralize the plate-to-grid capacitance. This eliminates the feedback without a resulting loss of amplification. This small fixed condenser is called the *neutralizing condenser.*

One end of the neutralizing condenser is connected to the grid of the tube while the other end is connected to the bottom of the primary of the radio-frequency transformer. The B+ is brought to a tap on this primary near the bottom of the coil.

This neutralizing condenser acts as a storage tank and electrons which without it would have been sent oscillating in the grid circuit are instead stored on its negative plate. The action is as though a flow of electrons equal to the feedback, but opposite in direction, were taking place. The opposing streams of electrons cancel out and there is no feedback.

Feedback due to capacitance within the tube is eliminated in modern sets by using tubes of the screen-grid class. We will discuss this more fully in the chapter dealing with types of tubes.

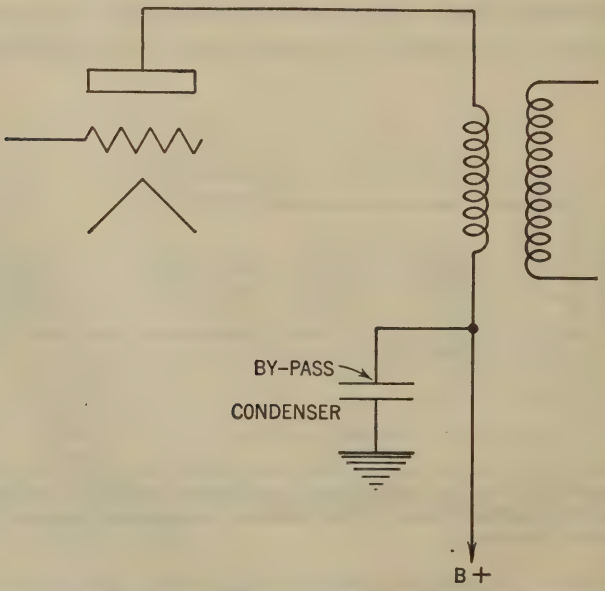


Figure 135. How a fixed condenser is used to by-pass any radio-frequency current leaking across the B supply.

162. Correcting Leakage by a By-pass Condenser

Another type of distortion we may encounter in the radio-frequency amplifier is due to the leakage of radio-frequency current from the grid circuit to the fluctuating direct current in the plate circuit of the amplifier tube. This leakage may take place through the B battery or the B eliminator.

This difficulty is remedied by providing a separate path for any radio-frequency current which finds itself in the plate circuit.

A fixed condenser whose value is about .006 μfd. is connected from the B+ terminal of the primary of the radio-frequency transformer to the ground. Then any radio-frequency current leaking across the B battery flows through the condenser to the ground (which is an easy path for radio-frequency current), rather than through the primary of the radio-frequency transformer (which presents a high resistance to radio-frequency currents). We call such a fixed condenser a *by-pass condenser.*

163. A Radio-frequency Choke Coil

We use a slightly different device to prevent any radio-frequency current that finds itself in the plate circuit of the detector tube from going into the audio-frequency amplifier, where it may cause some distortion.

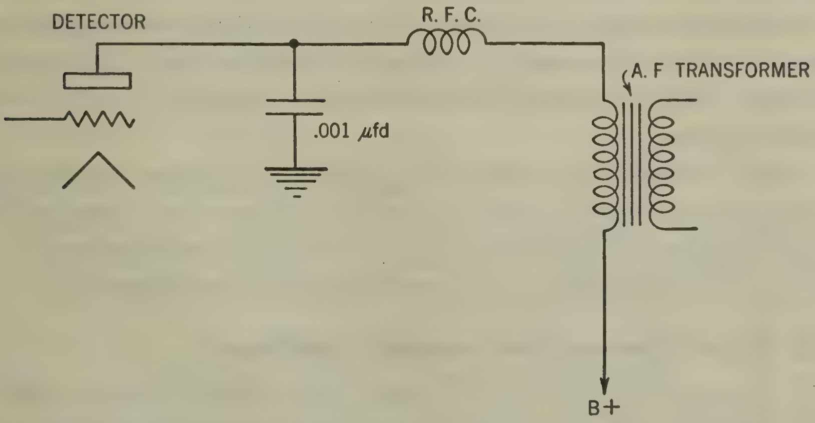


Figure 136. How a radio-frequency choke coil (R. F. C.) and by-pass condenser are used to keep stray radio-frequency currents from leaking into the audio-frequency amplifier.

Between the plate and the primary of the first audio transformer we connect a small inductance whose value is about 2½ millihenries. We call this inductance a *radio-frequency choke coil.* This choke coil offers a high resistance to the radio-frequency current, but not to the fluctuating direct current. To permit the radio-frequency current to escape we connect a small fixed condenser of about .001 μfd. from a point between the plate and the choke coil to the ground.

As in the case of audio-frequency amplification, a negative bias is placed on the grid of the radio-frequency amplifier tube to prevent distortion. Here, too, care must be taken not to make this negative bias too great, else detection will take place. (See Paragraph 106.)

164. Ganging of Variable Condensers

It is customary to use two stages of tuned radio-frequency amplification before the detector of the receiving set. Using fewer than two stages means not enough amplification, while using more makes it extremely difficult to control oscillations. If you examine Figure 126 you will see that such a receiver, using two stages of tuned radio-frequency amplification, has three variable condensers which must be manipulated to bring in the desired station. Since all three tuned circuits are very nearly alike, the variable condensers, too, will be meshed or unmeshed to about the same degree for receiving any given station.

It becomes logical, therefore, to connect all three variable condensers so that they may be operated simultaneously by turning one dial. This process of connecting the variable condensers is called *ganging.*

Early methods of ganging the variable condensers consisted of hooking them up with gears or a belt. This soon gave way to the simpler method of mounting all three variable condensers on one shaft. We now speak of a *three-gang variable condenser.*

165. Use of Trimmers with Variable Condensers

It is quite obvious that all three tuning circuits must be identical if the set is to function properly with ganged condensers. It is impossible, however, to make two coils or two variable condensers that are absolutely identical. Small variations are bound to creep in.

To overcome these slight discrepancies, a very small condenser, called a *trimmer,* is connected across each variable condenser of the tuning circuits. This trimmer usually consists of two metal plates, about ½ in. square, that are separated by a sheet of mica. Turning a screw separates the plates or brings them closer together, thus varying the capacitance of the trimmer. This small condenser is usually mounted at the side of the variable condenser.

These trimmers are adjusted to compensate for the discrepancies in the various tuning circuits. Their action is to add a slight amount of capacity to a tuning circuit to make the natural frequency of that circuit equal to that of all the other tuning circuits. Once adjusted, the trimmers are left in those positions. This process of matching up the various tuning circuits of a radio receiver is called *aligning the set.*

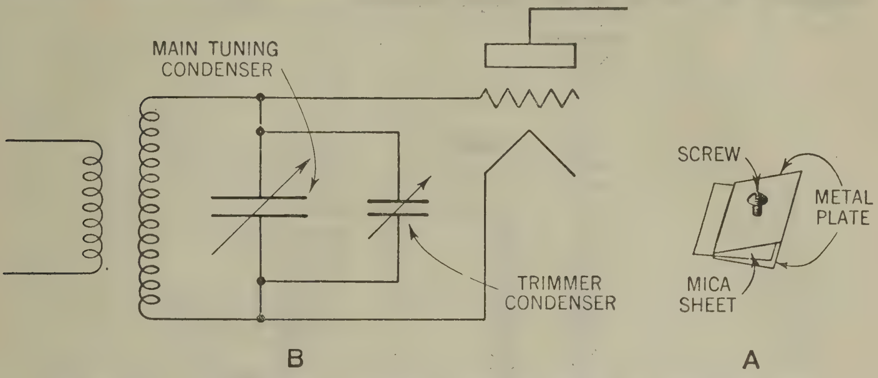


Figure 137. **A—Trimmer condenser used to align the radio-frequency amplifier stages.**
B—Circuit showing how the trimmer is connected across the main tuning condenser.

166. Use of Trimmers on Aerials

While on the subject of the trimmer condenser, it should be noted here that in modern practice one of these trimmers, called the *aerial trimmer,* is usually connected in series with the aerial-ground system (see Figure 138). The effect of this small condenser is to lengthen or shorten the aerial electrically.

This change in the aerial is desirable because each set will work most efficiently with an aerial of a certain length. Of course, you may go up on the roof and snip off some of the wire from the aerial, but it is much simpler to adjust the aerial trimmer until the signals are at their loudest. Once set, the trimmer is left alone until a new aerial is put up.

167. Radio Amplification Compared to Audio Amplification

In comparing our two types of amplification we must remember that they complement each other. We cannot use too many stages of either radio-frequency or audio-frequency amplification without running into oscillations, noises, or distortion of signals. Our modern receiving set therefore usually consists of two stages of radio-frequency amplification, the detector, and two or three stages of audio-frequency amplification.

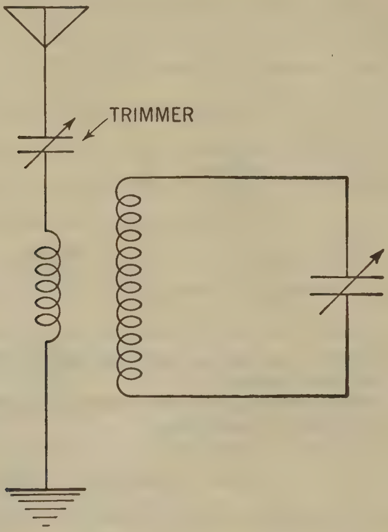


Figure 138. **Use of trimmer condenser to adjust the aerial to the radio receiver.**

A stage of tuned radio-frequency amplification has certain advantages over a stage of audio-frequency amplification. First of all, the sensitivity of the set is increased by radio-frequency amplification. In addition, the selectivity of the receiver is improved. Further, stage for stage, radio-frequency amplification gives greater gain than audio-frequency amplification.

On the other hand, the power output of the audio-frequency amplifier is greater than that of the radio-frequency amplifier. Under normal conditions, the radio-frequency amplifier and detector cannot operate a loudspeaker. Currents large enough for this purpose do not flow in their plate circuits.

Another feature of the audio-frequency amplifier is that it is normally more stable than the radio-frequency amplifier. If the set is properly designed we have no oscillations in the audio-frequency stages and need not neutralize the internal capacitance of the tube.

Since the audio-frequency stage does not require any controls

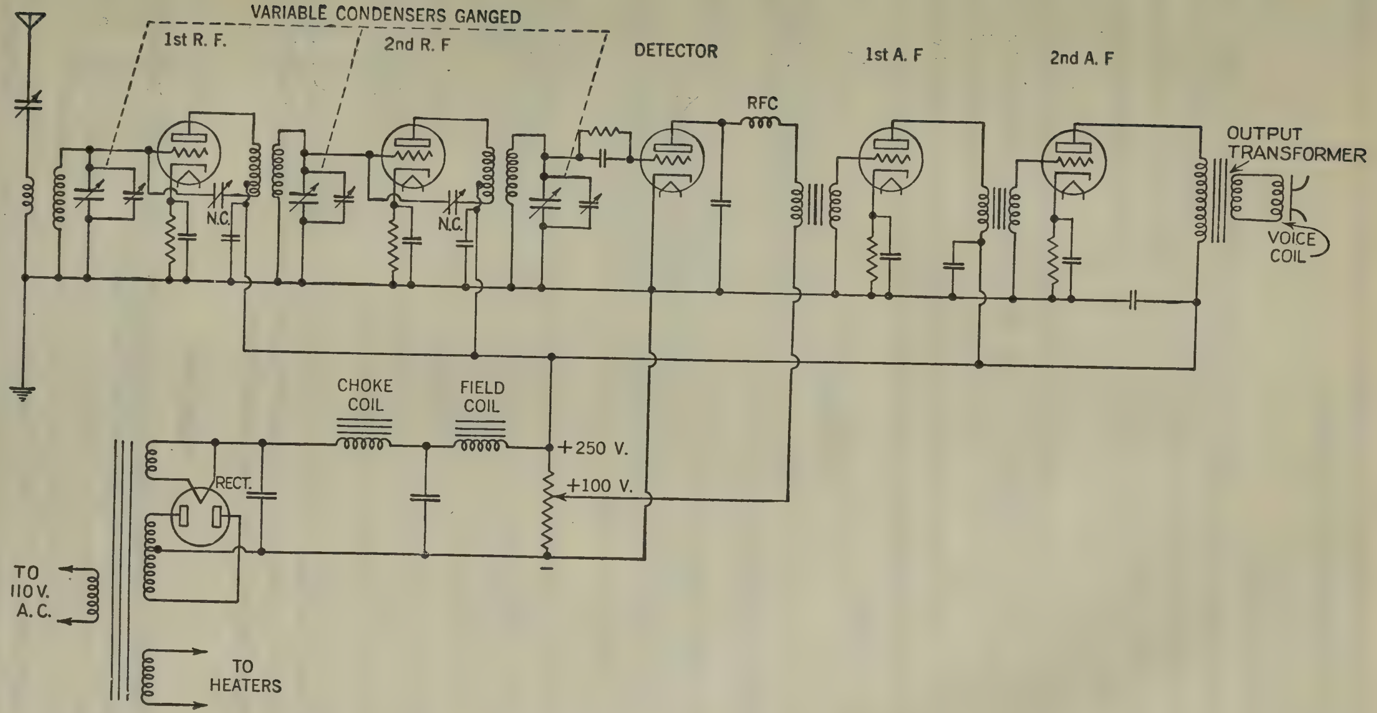


Figure 139. Circuit for a complete tuned radio-frequency receiver.

that need be manipulated, we are not troubled with such things as ganging or alignment of circuits.

168. The Five-tube Set

Figure 139 shows the circuit of a five-tube receiver with two stages of neutralized tuned radio-frequency amplification, a detector, and two stages of transformer-coupled audio-frequency amplification. This set is known as a *tuned radio-frequency* (T.R.F.) *receiver.*

The dotted lines connecting the three variable condensers show that they are ganged together. For the sake of simplicity the diagram does not show the connections of the filaments of the tubes, or the dotted lines indicating shielding around the antenna coupler, the radio-frequency transformers, and the radio-frequency and detector tubes.

SUMMARY

1. It has been found necessary to amplify the radio-frequency signals before transforming them into audio frequencies in order to obtain reception from distant radio stations.

2. The system developed to produce amplification of the radio-frequency currents is called the **tuned radio-frequency amplifier.**

3. The tuned radio-frequency amplifier employs a transformer whose secondary is tuned by means of a variable condenser, similar to that of the antenna coupler.

4. Two stages of tuned radio-frequency amplification, together with the tuner connected to the aerial-ground system, provide three tuned circuits. This arrangement gives great sensitivity as well as selectivity.

5. To avoid feedback from the radio-frequency amplifying system, several precautions must be taken, namely: use of narrow coils; setting coils at right angles to one another; shielding coils and tubes by metal covers; correcting influence of capacitance in tubes by resistors, condensers, or choke coils.

6. Modern five-tube sets have two stages of tuned radio-frequency amplification, two stages of audio-frequency amplification, ganged condensers, and shielded tubes and transformers.

GLOSSARY

Aerial Trimmer: A small variable condenser in the aerial circuit used to adjust the length of the aerial electrically.

Alignment: The process of adjusting the tuned circuits of a T.R.F. receiver so that all of them have the same natural frequency.

By-pass Condenser: A fixed condenser that shunts to the ground any unwanted radio-frequency currents, thereby preventing distortion of the signal.

Feedback: The transfer of electrical energy from the plate circuit of a tube to a preceding grid circuit. This is usually undesirable and produces distortion of the signal. (But see Regeneration, Par. 96.)

Ganged Condensers: Variable condensers, so hooked up that they turn simultaneously from a common shaft.

Neutralization: The elimination of the feedback due to the interelectrode capacitance between the plate and grid of the tube.

Neutralizing Condenser: A small condenser connected in such a way as to neutralize the capacitance between the plate and grid of a tube.

Radio Frequency: The frequency of the radio wave. Those in the broadcast band range between 550 kc. and 1,600 kc. per second.

Radio-frequency Amplifier: An amplifier that amplifies the radio-frequency current from the tuning circuit before feeding it into the detector.

Radio-frequency Choke Coil (R.F.C.): A coil of many turns offering a high resistance to radio-frequency currents, but not to low-frequency currents.

Radio-frequency Transformer: A step-up transformer, usually wound with an air core, used to couple radio-frequency electrical energy from one circuit to another.

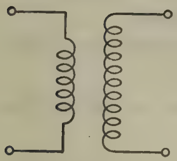
Shielding: The act of surrounding a current-carrying device by a metal container to keep magnetic fields in or out.

Trimmer: A small variable condenser connected across the large tuning condenser used to adjust the latter (see *Alignment*, above).

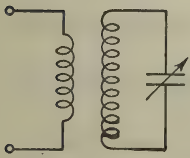
Tuned Radio-frequency (T.R.F.) Receiver: A receiver using one or more tuned radio-frequency amplifier stages, a detector, and one or more audio-frequency amplifier stages.

Tuned Radio-frequency Transformer: A radio-frequency transformer whose secondary is tuned by a variable condenser.

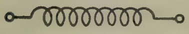
SYMBOLS



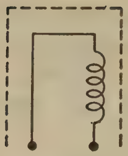
Radio-frequency transformer.



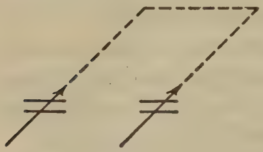
Tuned radio-frequency transformer.



Radio-frequency choke coil.



Shielded coil.



Ganged condensers.

QUESTIONS AND PROBLEMS

1. What is the chief fault of a receiver using a regenerative detector and two stages of audio amplification?
2. How may we overcome the weakness discussed in question 1?
3. What is meant by a radio-frequency amplifier?
4. How do we couple radio-frequency amplifiers to each other and to the detector?
5. In what way does a radio-frequency transformer differ from an audio-frequency transformer?
6. Why do we gain more selectivity by using several stages of tuned radio-frequency amplification?
7. Draw a sketch of a circuit from the aerial and ground system to the detector, using two stages of tuned radio-frequency amplification.
8. List several advantages of tuned radio-frequency stages over untuned radio-frequency amplifier stages.
9. How do we prevent the stray magnetic fields developed by our radio-frequency transformers from producing unwanted voltages in other parts of our receivers? Mention three devices used.
10. To what do we usually connect a shield?
11. What is the source of feedback or regeneration in a radio-frequency amplifier stage, and what does such feedback cause?
12. Explain the condenser action or capacity effect between the plate and grid of the triode radio-frequency amplifier stage.
13. Explain the losser method of oscillation control of a radio-frequency triode amplifier.
14. Explain the neutralization method of oscillation control of a radio-frequency triode amplifier.
15. What is the most modern method of oscillation control of radio-frequency amplifiers?
16. How do we prevent unwanted radio-frequency currents from getting into the B battery or B eliminator?
17. Describe the behavior of a R.F.C. (radio-frequency choke coil).
18. What is the purpose of ganging condensers?
19. Why do condensers in tuned radio-frequency amplifiers have trimmers on them?

20. What is meant by "aligning the receiver"?

21. What is the purpose of an aerial trimmer?

22. How many radio-frequency amplifier stages are usually used in a modern tuned radio-frequency receiver?

23. Compare radio-frequency amplification with audio-frequency amplification.

24. Draw a schematic diagram of a T.R.F. (tuned radio-frequency) receiver.

CHAPTER 24

Volume Control

Problem 1: *How is volume controlled in battery sets?*
Problem 2: *What problems arise in controlling the volume in nonbattery sets?*
Problem 3: *What devices are used to control the volume automatically?*
Problem 4: *How are modern sets wired for automatic volume control?*

Every radio receiving set must have some method for controlling volume or loudness of the sounds from the speaker. Otherwise, nearby powerful stations would blast through the loudspeaker

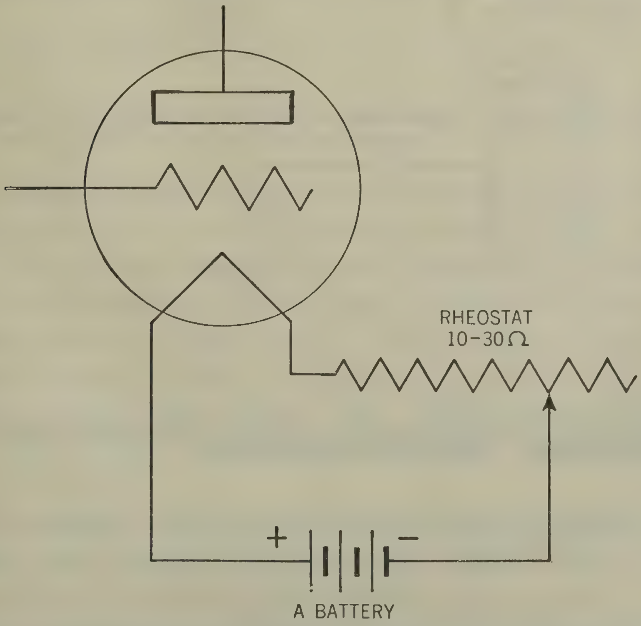


Figure 140. Rheostat in the filament circuit used to control volume.

with uncomfortable loudness and less powerful stations would be heard very faintly.

169. Volume Control in Battery Sets

Volume control for battery-operated sets is a relatively simple matter. The most common device is a rheostat of from 10 to 30 ohms connected in series with the A battery and the filament of the radio tube, as in Figure 140.

This rheostat controls the temperature of the filament and in this way controls the quantity of electrons emitted by the filament and therefore the plate current flowing in the plate circuit. This current in turn controls the loudness of the signal coming out of the loudspeaker.

Another method that is less frequently used is to connect a rheostat of about 250,000 ohms in the plate circuit of the tube (see Figure 141). This rheostat controls the positive charge placed on the plate by the B battery and in this way controls the plate current and thus the loudness of the sound.

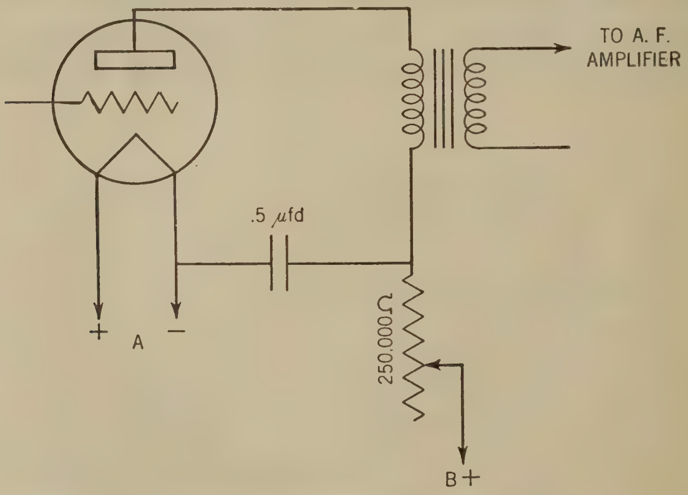


Figure 141. Circuit showing how a rheostat in the plate circuit is used to control volume. This device is unsatisfactory.

This rheostat must be by-passed by a fixed condenser of about .5 μfd. to filter off any radio-frequency currents that may leak through. This method is rarely used, as it has a tendency to detune the set unless the value of the rheostat is kept very high and then it does not permit a large positive charge to be placed on the plate.

170. Volume Control on House-current Sets

In the nonbattery set, it is desirable to keep the filament current constant. This rules out the rheostat in the filament circuit. Other methods of volume control were developed.

One method is to connect a 25,000-ohm potentiometer across the primary of the antenna coupler and to connect the aerial to the sliding arm, as in Figure 142.

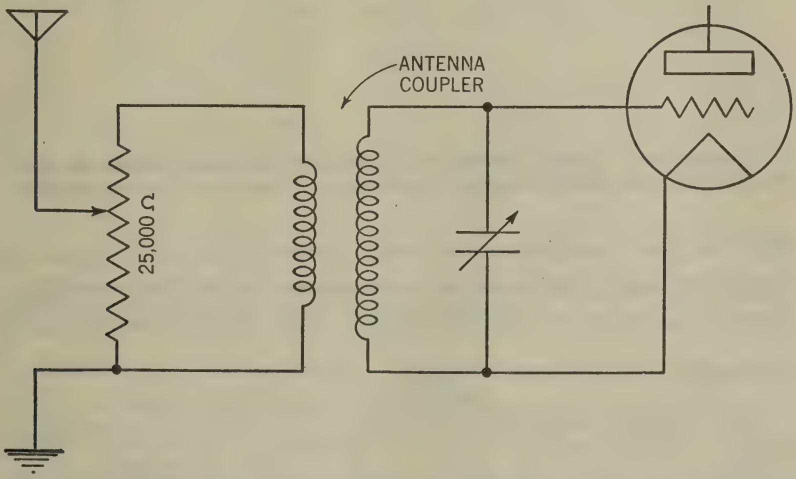


Figure 142. Circuit showing how a potentiometer across the primary of the antenna coupler is used as a volume control.

This hookup controls the amount of current fed into the tuner and thus controls the sound ultimately coming from the loudspeaker. This method suffers from the disadvantage that although it cuts down the amount of electrical energy picked up by the aerial and therefore the amount of outside static or outside electrical interference, it does not reduce the amount of electrical interference created inside the set itself. These latter interferences come through and are amplified within the set. The result is that the set is quite noisy.

Another method, shown in Figure 143, is to connect a 5,000-ohm rheostat across the primary of the transformer in the plate circuit of the second radio-frequency tube.

This method has the advantage that it cuts down the electrical interference in the radio-frequency stages within the set at the same time as it cuts down the signal strength by dissipating a part of the plate current of the second radio-frequency stage.

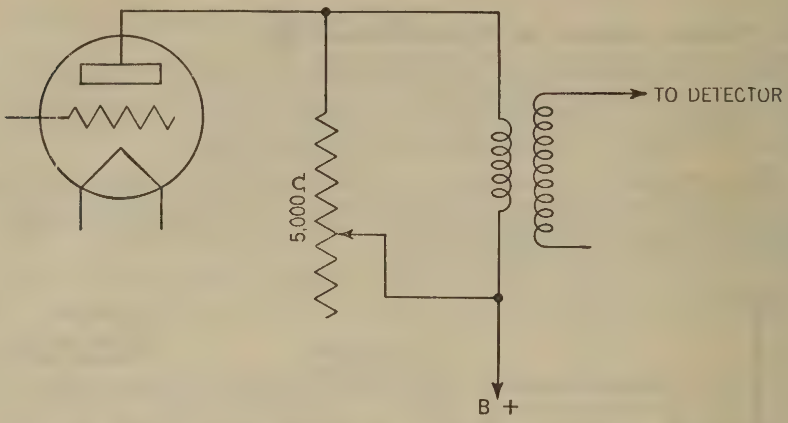


Figure 143. Circuit showing how a rheostat connected across the primary of the last radio-frequency transformer is used as a volume control.

Still another method of volume control, shown in Figure 144, is to connect a 500,000-ohm potentiometer across the secondary of the first audio-frequency transformer. The grid of the first audio-frequency tube is connected to the sliding arm. The potentiometer then controls the charge placed on the grid of the tube.

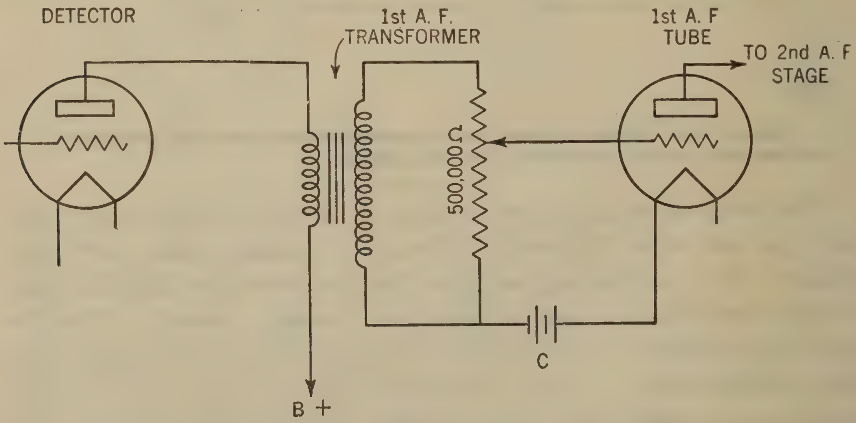


Figure 144. Circuit showing how a potentiometer is connected across the secondary of the first audio-frequency transformer to act as a volume control.

Sometimes the method shown in Figure 144 is combined with that shown in Figure 143. The 500,000-ohm potentiometer and

5,000-ohm rheostat are mounted on the same shaft so that, although they are insulated from each other, they are rotated together by the same control knob.

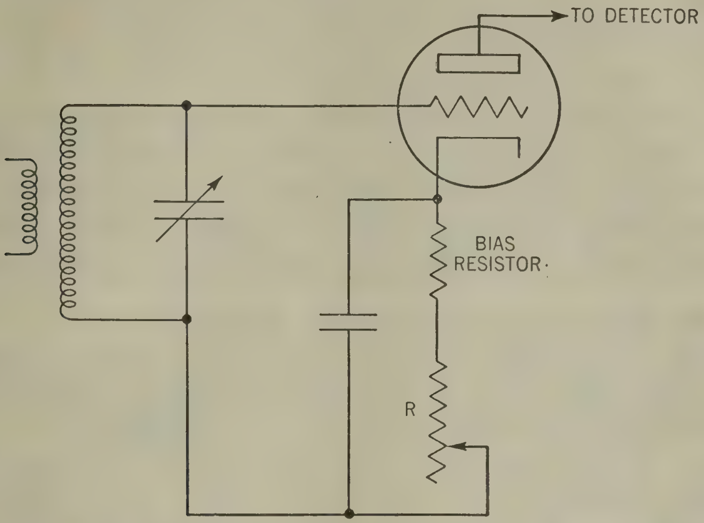


Figure 145. Circuit showing how a rheostat (R) is placed in series with the bias resistor to act as a volume control.

171. Control of Volume when a Cathode-type Tube Is Used

The use of a cathode and a grid bias resistor furnishes us with a simple and effective means of controlling the volume. Hooked up in series with the bias resistor is a rheostat, as in Figure 145.

By varying the rheostat, the resistance used to place a negative

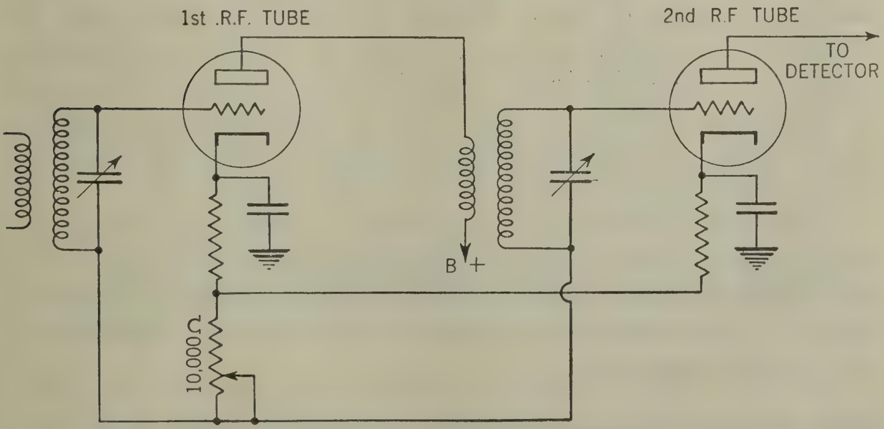


Figure 146. Circuit showing how the rheostat used as a volume control varies the grid bias of both radio-frequency tubes.

charge on the grid of the amplifier tube is made larger or smaller. (This resistance now consists of the bias resistor plus the resistance of the rheostat.) This variation in turn makes the grid more negative or less negative. The more negative the grid, the smaller the number of electrons flowing to the plate and the less the amplification. (See Chapters 15 and 20.)

This rheostat may be connected to the bias resistors of one or more tubes and thus control the amount of amplification supplied by these tubes. The value of this rheostat varies from about 5,000 to 50,000 ohms, depending upon the number of tubes controlled. The more tubes so controlled, the lower the value of the rheostat.

172. The Need for Automatic Volume Control

While on the subject of the volume of the sound coming out of the radio receiver, let us consider two problems which must be solved for the greater enjoyment of radio reception.

First: Having tuned in a fairly weak station, you have turned the volume control up to give a loud sound. Now you tune in another station. As you turn the dial you happen to pass a powerful station. Since the volume control is turned up to "loud," the new station comes in with an earsplitting blast.

Second: This is the more serious problem. You will soon become acquainted with the nuisance of *fading*. The signal will rise and fall, grow louder and softer. We say the signal "fades in" and "fades out."

Just why a radio wave behaves in this manner is not fully known, although we have theories that tend to explain it. We think it is due to the shifting of a layer of electrified air particles, called the "Heaviside layer," far above the surface of the earth. It is not our purpose at this point to discuss this phenomenon, except to recognize that it exists and tends to spoil our enjoyment of the radio program (Chap. 35, Vol. II).

If we had a method of automatically turning our volume control to "loud" when the signal became weaker and to "soft" when the signal became stronger, both of these problems would be solved. This task is accomplished by the *automatic volume control* (abbreviated A.V.C.).

173. Automatic Volume Control by Regulation of Grid Bias

How automatic volume control operates is fairly easy to understand. A portion of the signal current is taken off (usually before it reaches the detector), and rectified to direct current. Thus the greater the signal strength, the larger the resulting direct current; the smaller the signal strength, the less the direct current. This direct current is then fed to the grid returns of the amplifying tubes where a negative bias is placed on the grids.

Since greater signal strength yields larger direct current, the grids become more negative. This negative charge on the grids cuts down the amplification of the tubes. Contrariwise, the smaller the signal strength, the less the direct current and the less negative the grids. The effect of less negative grids is to increase the amplification of the tubes.

The net effect is that the greater the signal strength, the less the tubes will amplify it, and the less the signal strength, the more the tubes will amplify it. This arrangement tends to keep the volume of sound coming out of the loudspeaker at a constant level and helps to eliminate blasting and fading.

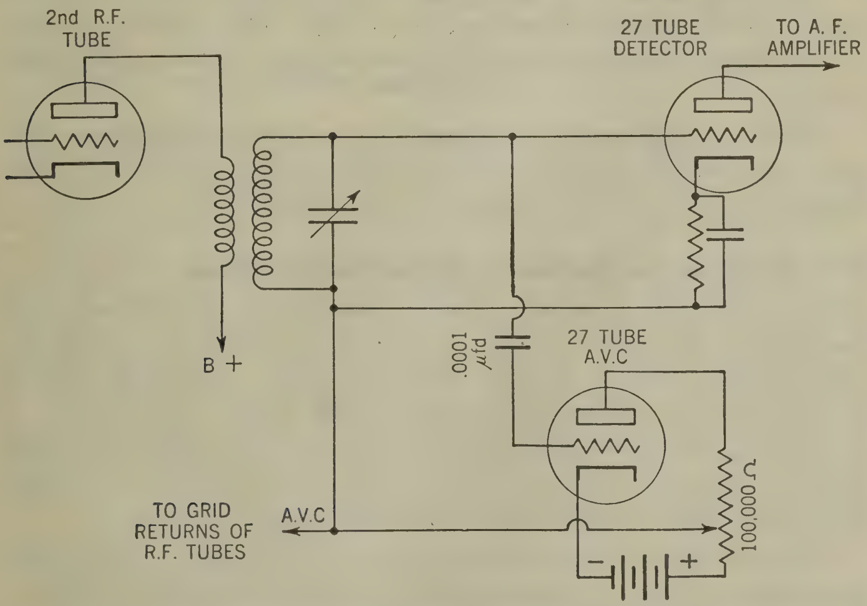


Figure 147. Circuit showing hookup using a 27 tube to obtain the automatic-volume-control voltage. Note that the detector is of the grid-bias type.

One method of obtaining automatic volume control is shown in Figure 147. Note that the detector tube is connected up as a grid-bias detector, using a bias resistor in the cathode circuit. The grid of the automatic-volume-control tube is connected to the grid of the detector tube through a .0001-μfd. condenser. Thus a small part of the signal voltage is tapped off. The greater the signal, the more positive the charge placed on the grid of the detector. Likewise, a greater positive charge is placed on the upper plate of the .0001-μfd. condenser. Accordingly more electrons are drawn from the grid of the automatic-volume-control tube to the lower plate of the condenser and therefore a greater positive charge is placed on the grid of the automatic-volume-control tube.

This charge causes more electrons to stream across from the cathode of the automatic-volume-control tube to its plate. Hence more electrons will flow through the plate circuit and through the sliding arm of the 100,000-ohm potentiometer to the grid returns of the amplifier tubes.

This electron surge in turn places a greater grid bias or negative charge on the grids of these amplifier tubes. The flow of electrons to the plates of these tubes is cut down and less amplification results.

The louder the signal, therefore, the less the amplification. The smaller the signal, the less negative bias on the grids of the radio-frequency tubes and the greater the amplification.

174. Details of the Automatic-volume-control System

By means of a voltage divider across the B eliminator, as described in Chapter 18, we can get the voltage to replace the plate battery as well as that needed to place a negative bias on the grid of the automatic-volume-control tube (Figure 148). A 2-megohm resistor is used as a grid leak and the cathode and plate are by-passed by .1-μfd. condensers to the ground to eliminate any radio-frequency current that may have leaked through.

The 250,000-ohm resistor and the .5-μfd. condenser in the automatic-volume-control line are used to filter out unwanted fluctuations just as the choke coil and filter condensers do in the B eliminator. The arrangement of these devices is shown by the wiring diagram in Figure 148.

The potentiometer of 100,000 ohms limits the automatic-volume-control voltage. The loudest station is tuned in and the potentiometer is adjusted manually until a comfortable volume is reached. It is left in this position and no signal will come through with a greater volume. Blasting is eliminated. Should the signal strength drop, however, the amplification of the radio-frequency tubes is increased to bring the volume up.

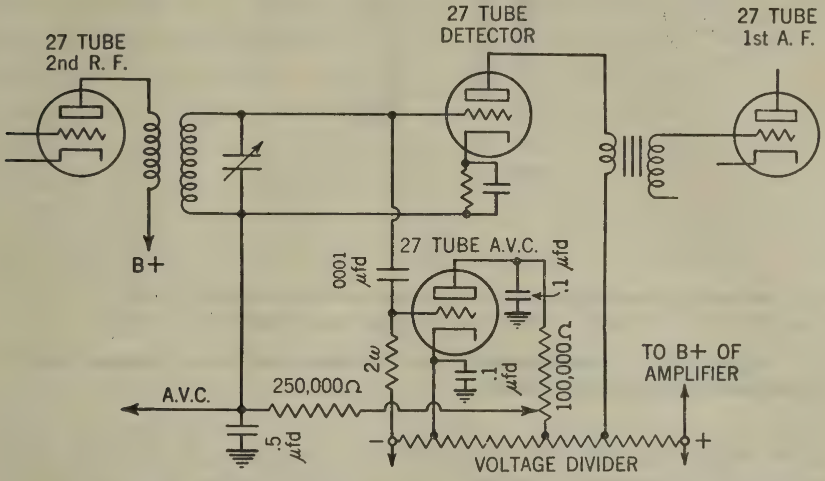


Figure 148. Complete automatic-volume-control circuit showing the by-pass condensers and filter resistances.

175. Replacing the Triode by a Diode for the Detector

Since the action of the automatic-volume-control tube is to rectify the signal current and feed it to the grid returns of the radio-frequency amplifier tubes, it becomes obvious that a diode may be used for this purpose instead of the triode shown in Figure 148. A logical step for improvement is to employ a circuit using a diode tube both as a detector and as an automatic-volume-control tube. The advantage of a diode detector over a triode is that the diode does not distort the signal. The disadvantage of the diode detector is that it adds no amplification. This defect, however, is overcome through the great amplification possible from the radio-frequency stages.

Figure 149 shows this circuit.

As in the case of the ordinary diode detector (see Chapter 14), the signal is impressed on the plate of the diode. When the plate is negative, no electrons are attracted from the cathode. When the plate is positive, electrons are attracted and are set flowing around the plate circuit from the plate to points 1, 2, 3, 4, 5, and back to the cathode. The more positive the plate, the greater the plate current.

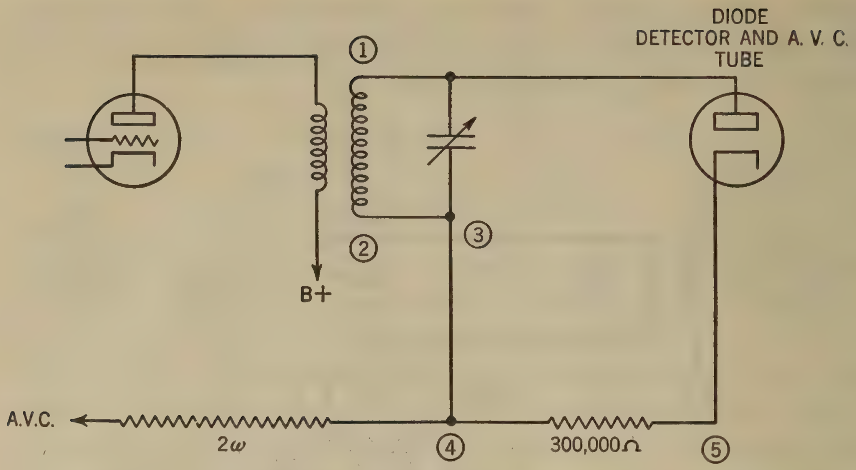


Figure 149. Circuit showing how the diode acts as a detector and automatic-volume-control tube.

At point 4, the electron stream divides. A portion flows through the 2-megohm resistor and thus furnishes the automatic-volume-control voltage which is applied to the grid returns of the radio-frequency amplifiers.

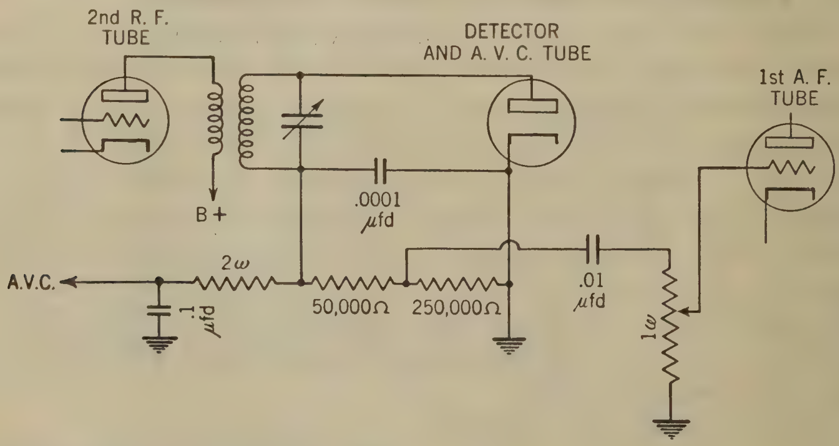


Figure 150. Circuit showing complete automatic-volume-control circuit.

176. The Complete Automatic-volume-control System

Since the 300,000-ohm resistor furnishes an easier path for the flow of electrons than does the 2-megohm resistor, the greater part of the electron stream flows toward point 5. This part is fed into the audio amplifier as shown in Figure 150.

The 300,000-ohm resistor consists of two resistors in series, one of 50,000 ohms and the other 250,000 ohms. The major electron stream flows through the 50,000-ohm resistor to the junction of these two resistors. Here the 250,000-ohm resistor holds back the electrons and forces them to go to the plate of the .01 μfd. coupling condenser that couples the diode detector with the grid of the first audio-frequency amplifier tube. You recognize, of course, that this system really is the same as a stage of resistance-coupled audio-frequency amplification (see Chapter 17). The 1-megohm potentiometer controls the strength of the electrical charges placed on the grid of the first audio-frequency amplifier tube and thus acts as a manual volume control.

The .0001-μfd. condenser by-passes to the ground the unwanted radio-frequency currents that may have leaked into the diode plate circuit. The 2-megohm resistor and .1-μfd. condenser in the automatic-volume-control line are there to smooth out the automatic-volume-control voltage and to remove any audio-frequency currents that may be present.

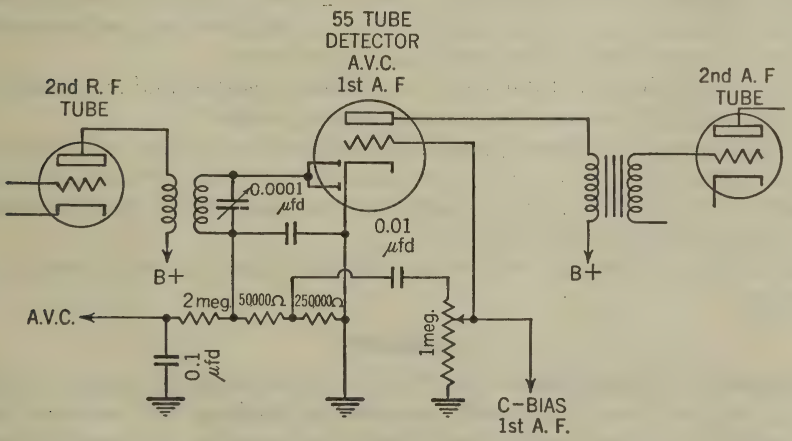


Figure 151. Circuit showing how the type 55 tube is used as a detector, automatic volume control, and first audio-frequency amplifier.

177. Combining Two Tubes in One

Tube manufacturers soon came out with a tube that combined the diode and triode in one envelope (glass bulb). Such a tube is the type 55. This tube has a single cathode, one surface of which emits electrons to the diode plate, while the other surface sends electrons to the grid and plate of the triode. Actually, there are two diode plates in this tube, but for our purpose we connect them together and treat them as one plate. The advantage of such a tube is that in one envelope we have the diode detector, the automatic-volume-control tube and the first audio-frequency amplifying tube. Figure 151 shows how it is connected.

Other automatic-volume-control circuits have been developed, but the principle upon which they work is the same as that described here.

SUMMARY

1. The loudness of the signals coming from the speaker is known as **volume.**

2. In battery sets, volume is easily controlled by a rheostat that regulates the current in the filament and hence the temperature and the number of electrons emitted.

3. In nonbattery sets the filament current needs to be kept constant, so that the rheostat control in the filament circuit is not practical.

4. Control of volume by a potentiometer across the primary of the antenna coupler is less satisfactory than the use of a rheostat across the primary of the transformer in the plate circuit of the second radio-frequency tube.

5. Another method, sometimes combined with the last method mentioned in item 4, is to use a high resistance (500,000-ohm) potentiometer across the secondary of the first audio transformer.

6. A cathode-type tube with a grid-bias resistor and a rheostat is a good practical method for manual volume control.

7. **Automatic volume control** is achieved by devices which give a greater negative grid bias when greater currents come through, and conversely. This negative bias in turn controls directly the amplification in the radio-frequency amplifiers.

8. Modern tubes of the 55 type combine the triode and diode in one envelope.

GLOSSARY

Automatic Volume Control (A.V.C.): An automatic control of volume in the radio receiver which operates by making the receiver more sensitive to weak radio signals and less sensitive to powerful radio signals.

Fading: An undesired weakening of the radio signal.

Heaviside Layer: A layer of electrified air, consisting of charged particles called ions, from sixty to two hundred miles above the surface of the earth, which acts as a reflector for radio waves. Changes in this layer are believed to be the chief cause of fading. The layer is also known as the Kennelly-Heaviside layer or ionosphere.

Manual Volume Control: A control of volume, usually a variable resistor, which can be manipulated by the person operating the radio receiver.

QUESTIONS AND PROBLEMS

1. How is the volume of a battery receiver usually controlled?
2. What are the methods of manual volume control used in modern A.C. or A.C.-D.C. power-supply receivers?
3. Why is it desirable to have automatic volume control in a receiver?
4. What is one possible cause of fading?
5. How is automatic volume control accomplished in a receiver?
6. Draw the diagram of a diode detector with automatic volume control.

CHAPTER 25

Tone Control

Problem 1: *How is the tone of sound waves related to the frequency?*

Problem 2: *What factors in radio receiving sets affect tone?*

Problem 3: *How do methods of tone control separate high-pitched tones from low-pitched tones?*

In the last chapter you learned how the volume of sound coming out of the loudspeaker may be controlled. In this chapter you will learn how we control the tone of the radio receiving set.

178. What Is Meant by "Tone"?

As you know, sound is caused by air waves; these strike our eardrums and produce the sensation we call "hearing." To describe a sound we say not merely that it is loud or soft, but we also describe its tone. The tone depends upon the frequency of the sound wave. The human ear can detect frequencies from about 30 cycles to 15,000 cycles per second.

Those sound waves whose frequencies are low are described as *deep, bass* or *low-pitched sounds.* Those whose frequencies approach 15,000 cycles per second are called *shrill, treble,* or *high-pitched* sounds. Those whose frequencies fall in between are called *middle-register* sounds.

Music and speech, generally, are not composed of sounds having only one frequency. High-frequency and low-frequency sound waves usually are merged to produce a distinctive combination. If the result of mixing these sound waves of different frequencies is a sound whose predominant tone is that of the middle register, we say the sound has a *normal* tone.

If the sound has a preponderance of high-frequency sound waves, we say the tone is *high-pitched.* Women's voices generally fall into this category.

If the sound has a preponderance of low-frequency sound waves, we say the tone is *low-pitched.* Men's voices generally fall into this category.

The tone of the sound coming out of the loudspeaker of the radio receiver then may be normal, high-pitched, or low-pitched, depending upon the combination of high-frequency and low-frequency sound waves present.

179. What Determines the Tone of a Radio Receiver?

Since tone is an audio-frequency phenomenon, we must look for the answer in the audio-frequency part of the set, that is, in the events after the electron impulses have reached the plate of the detector tube. Investigation shows that the audio-frequency amplifier usually does not amplify all the frequencies at the same rate. Thus the high frequencies may be amplified more than the low frequencies, or vice versa. Or some intermediate frequencies may be amplified more or less than those at either end of the audio scale.

Furthermore, the loudspeaker does not respond to all frequencies in like degree. The early speakers of the metallic-horn type failed to bring out the deep notes. The result was an unpleasant "tinny" sound.

Good practice in designing a radio set is to match the loudspeaker to the audio-frequency amplifier so that one compensates for the variations of the other. The result is a fairly uniform reproduction of sound at all frequencies.

180. The Problem of Control

It also is desirable to be able to control the tone of a radio set. Speech is clearer when it is somewhat higher pitched. On the other hand, many people prefer their music somewhat lower pitched. Some people do not enjoy listening to a soprano voice because of the preponderance of high-frequency tones.

The ideal method for controlling the tone of a radio receiver would be by means of controls which would regulate the amplification of the high-frequency notes and low-frequency notes separately. Such a method does exist, but it is quite complicated. It is used almost exclusively for public-address systems and studio purposes. The ordinary radio receiver uses a much simpler method which closely approximates the ideal method in results.

There is a peculiarity about human hearing. Take a sound of normal tone. The high frequencies and low frequencies are present in certain proportions. If now we amplify the low frequencies, we get a bass, low-pitched sound which has the same normal amount of the high-frequencies, but more of the low frequencies.

Take the same sound of normal tone described above. Now remove some of the high frequencies. Although we have not added any new low frequencies, nevertheless we get the effect of a bass, low-pitched sound. This is called *false bass.*

Similarly, if we remove some of the low frequencies from the normal tone, we get the effect of a high-pitched, treble tone. This is a *false treble.*

181. How to Separate High Pitch from Low Pitch

Our next problem is to devise a method of removing some of either the high or the low frequencies.

The electric currents flowing in the audio-frequency amplifier fluctuate within the audio range, that is, between 30 cycles and 15,000 cycles per second. These currents cause the diaphragm or cone of the loudspeaker to vibrate in step with them. Thus a current fluctuating at about 100 cycles per second will cause a deep note to come forth from the loudspeaker, while a current fluctuating at about 10,000 cycles per second will produce a high-

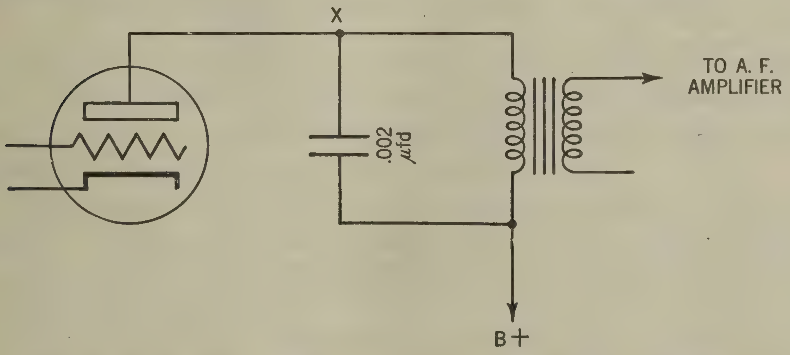


Figure 152. Circuit showing how a condenser is used to filter out some of the high-frequency current.

pitched note. Remember that when we speak here of high frequency, we mean high audio frequency and not radio frequency.

To remove some of the high-frequency current, we place a fixed condenser across the path of the audio-frequency current.

It may be shown that a condenser furnishes a path of lower resistance than that of the plate circuit to currents of high frequencies but not for currents of low frequencies. Hence the fluctuating current flowing in the plate circuit of the detector tube divides at point X (Figure 152). Some of the high-frequency current passes through the .002-μfd. condenser and goes on to the positive terminal of the B eliminator. The main part of the plate current, however, containing all the low frequencies, passes through the primary of the first audio-frequency transformer and is amplified. Since some of the high frequencies are missing from the sound emitted by the loudspeaker, our radio set now has a bass tone.

We can vary the amount of high-frequency current by-passed by the condenser by connecting a 500,000-ohm rheostat in series with it, as in Figure 153. The more the resistance in the circuit, the less the amount of high-frequency current that will be bypassed and therefore the more treble the tone.

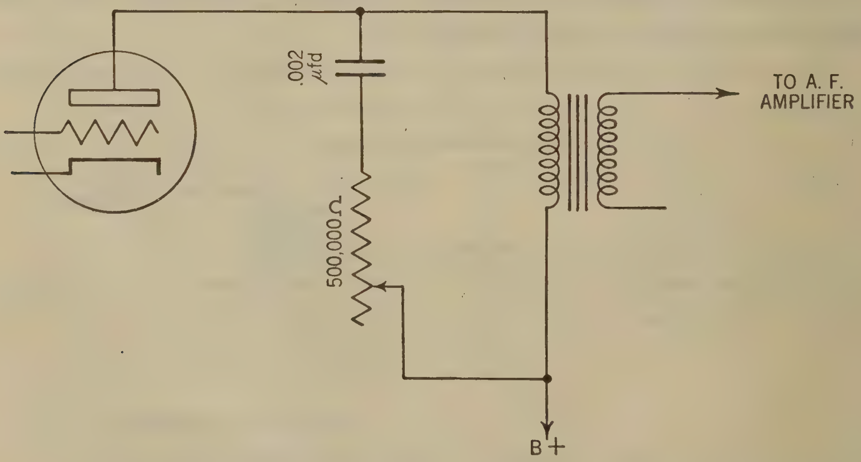


Figure 153. Circuit showing how a rheostat is connected in series with the condenser to control the amount of high-frequency current filtered out.

The combination of fixed condenser and rheostat is called a *tone control*. It may be placed anywhere in the audio circuit, across the primary of the audio transformer (as shown) or across the secondary. It may be applied to any of the audio-frequency stages.

182. Tone Control by Supplying an Alternate Path to the Ground

Another type of tone control is shown in Figure 154.

This tone control consists of two arms. In one arm, A, is a .1-μfd. condenser. In the other, B, a .1-μfd. condenser is connected in series with a choke coil of about 85 millihenries. One end of each arm is connected to the plate of the final audio-frequency tube. Across the other ends a 100,000-ohm potentiometer is connected with the sliding arm going to the ground.

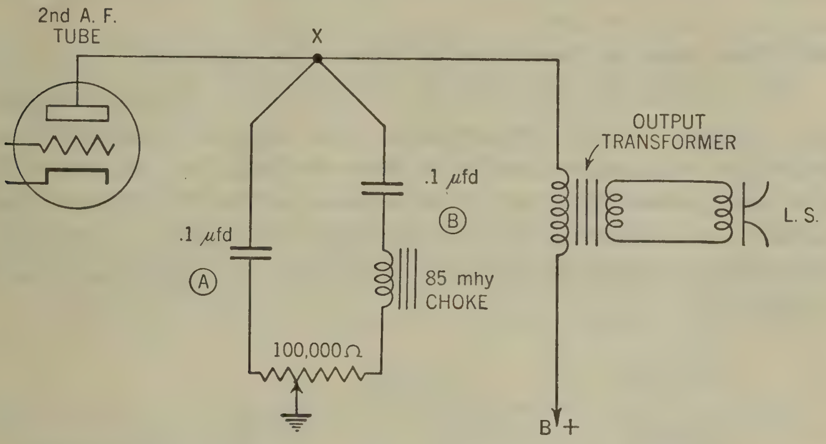


Figure 154. Circuit showing a "treble-bass" tone control.

The action of the choke coil is opposite to that of the condenser. It offers a higher resistance to currents of higher frequencies. Hence it conducts more readily the parts of the current with low frequencies.

First consider the circuit with the sliding arm of the potentiometer all the way to the left. None of the resistance is in arm A; it is all in arm B. Current flowing in the plate circuit of the audio-frequency tube divides at point X as described in Figure 152. Some of the high-frequency current is lost through the condenser. The main part of the current passes through the output transformer and our set now has a bass tone.

When the slider arm is all the way over to the right, the entire 100,000 ohms is in arm A. This prevents the loss of the high-frequency currents. As a result, the diverted current flowing from point X must now pass through arm B. Since the choke coil offers a high resistance to the high-frequency current, it is only low-frequency currents that pass through and go on to the ground. Since we have lost some of the low frequencies, our tone now is treble.

Varying the sliding arm of the potentiometer varies the amount of high or low frequencies lost and thus the tone of the set is controlled.

183. Tone May Be Controlled by Using Two Speakers

There is still another method of tone control that is sometimes used. Some sets have two speakers. One is a speaker which reproduces the low frequencies better than the high frequencies. The other reproduces the high frequencies better. Both of these speakers are connected to the output transformer by a potentiometer which controls the amount of current flowing through each (Figure 155).

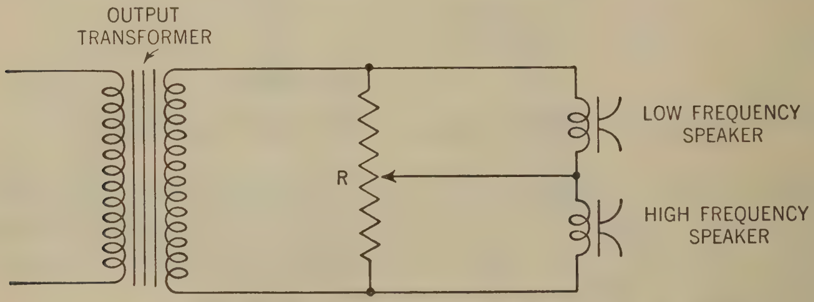


Figure 155. Circuit showing how tone control may be obtained through the use of higher-frequency and lower-frequency loudspeakers. The potentiometer (R) determines which speaker shall obtain the great current.

Thus if more current flows through the high-frequency speaker and less through the low-frequency speaker, the high frequencies are louder and the tone is treble. If the conditions are reversed the tone is bass. The potentiometer, then, acts as a tone control.

Different manufacturers of radio sets may use different types of devices for tone control but upon analysis of the circuits you will see that they usually are variations of the ones described here.

SUMMARY

1. Sounds having regular frequencies are called musical **tones.**

2. The frequency of a tone is related to its **pitch**: low pitch means low frequency and high pitch means high frequency.

3. The tones coming from a speaker are influenced both by the arrangement of the parts of the audio-frequency system and also by the kind of loudspeaker.

4. The principles of **tone control** that are made use of within the receiver are: (1) condensers offer a path of less resistance to high-frequency currents than to low-frequency currents. (2) Choke coils offer more resistance to high-frequency currents and less resistance to low-frequency currents.

5. The most successful tone control makes use of a divided circuit leading to the ground, in one arm of which is a condenser and in the other arm a choke coil. A slide arm on the potentiometer controls the tone by permitting more or less high-frequency current to pass through.

6. Two speakers having different qualities—one good for high pitch, the other for low pitch—may be hooked to one receiver. The tone can be controlled by varying the amounts of current in the two speakers.

GLOSSARY

Tone: The sound resulting from the mixture of air waves of different frequencies.

Bass Tone: The tone resulting when low frequencies are predominant. Also called *low-pitched tone.*

Middle-register Tone: The tone resulting when high and low frequencies are present in about equal proportions. Also called *normal tone.*

Treble Tone: The tone resulting when high frequencies are predominant. Also known as *high-pitched* or *soprano tone.*

Tone Control: An electrical circuit used to emphasize high- or low-frequency notes in a combination of sound frequencies. It usually consists of a fixed condenser and rheostat.

QUESTIONS AND PROBLEMS

1. Upon what does the tone of a sound depend?

2. What is the frequency range of human hearing?

3. What is meant by a bass tone? A middle-register tone?

4. What conditions in a receiver cause distortion or inaccurate reproduction of tone?

5. What should be the pitch of the tone of speech over the radio amplifier to make it clearer?

6. What must be the function of a tone control?

7. What peculiarities of hearing enable us to use a practical tone control?

8. What is a false bass?

9. What is a false treble?

10. Draw a sketch of a practical tone-control circuit.

11. In what part of a receiver circuit do we usually place a tone control?

12. What is the purpose of using two speakers in a receiver? How do they function?

CHAPTER 26

The Superheterodyne Receiver

Problem 1: *Why is not the tuned radio-frequency amplifier satisfactory?*
Problem 2: *What is the principle of beats?*
Problem 3: *How is the principle of beat currents applied to obtain sharp tuning over a wide range of frequencies?*
Problem 4: *What are the essential principles of the superheterodyne receiver?*

It is interesting to note how one great invention or discovery leads to other inventions or discoveries. Many examples of this are found in the history of radio.

After the invention of the system of tuned radio-frequency amplification, radio engineers began looking for means to correct the flaws and drawbacks of this circuit. This search led to the next improvement.

184. Faults of Tuned Radio-frequency Amplifiers

The drawbacks of the circuit were found to be in the inability to have a wide range of reception and at the same time sharp tuning.

To obtain maximum sensitivity and selectivity, the tuning circuit should have a natural frequency exactly equal to the frequency of the broadcasting station. But our tuning circuit is made so that we may tune in all frequencies lying in the broadcasting range, that is, from 550 to 1,600 kilocycles. To obtain this broad coverage a compromise is made in the design of our tuned radio-frequency transformer and some of the selectivity and sensitivity is sacrificed.

The ideal way would be to have a separate set of tuned radio-frequency transformers for each frequency received. This, of course, is impractical for home receivers.

185. The General Principle of a Superheterodyne

The invention of the superheterodyne receiver resulted from the experiments seeking to approach this ideal condition. In the system to which the name superheterodyne is given we have, instead of a separate set of tuned radio-frequency transformers for each frequency received, one set of tuned radio-frequency transformers that are tuned to one predetermined frequency. After selecting the radio station we desire, we change the frequency of the currents flowing in our receiver to that certain predetermined frequency and then feed it into our tuned radio-frequency amplifier.

In this manner we have the advantage of using tuned radio-frequency transformers that operate at only one frequency without the drawback of needing a separate set for each frequency. Our set is more selective and sensitive than the tuned radio-frequency set described in Chapter 23.

186. What Is Meant by "Beats"?

In order to understand how the frequency of the incoming signal is changed to that for which the radio-frequency transformers are tuned, you must first learn about the phenomenon of *beats*.

Strike middle C on the piano. The sound you hear has a frequency of 256 cycles per second. Now strike the note before it, B on the piano. This note has a frequency of 240 cycles per second. Now strike both keys together. The sound you hear is neither B nor C but a mixture of the two. If you listen closely you will notice that this new sound rises and falls in loudness or intensity. If you can time this rise and fall of sound you will notice that it occurs 16 times per second, the exact difference between the frequencies of B and C.

We call this rise and fall the *beat note*. Its frequency (that is, the number of beats) is equal to the difference between the frequencies of the notes producing it.

The production of beat notes occurs not only in the case of sound waves, but whenever any kind of waves of different frequencies clash or beat against each other. Thus, under certain conditions, light waves may produce beats. Also, radio waves of different frequencies may be mixed, resulting in beats whose frequency equals the difference between those of the two original waves.

Now we can explain how we are able to change the frequency of the incoming signal to that for which the radio-frequency transformers are tuned. The problem is to mix with the incoming signal another radio-frequency current whose frequency is such that the difference between the two is equal to the predetermined and desired frequency.

187. Forming Best Frequencies in the Receiver

Assume we have set our radio-frequency transformers so that their natural frequency is 175 kc. Let us suppose that we are receiving the signal from a station whose frequency is 1,000 kc. All we need do is to generate a radio-frequency current whose frequency is 1,175 kc. We mix this radio-frequency current with the incoming signal (1,000 kc.) and a *beat current* results whose frequency is 175 kc. (1,175 kc. — 1,000 kc. = 175 kc.) This 175-kc. beat current is fed into the radio-frequency transformers and amplification occurs at maximum efficiency. The idea is shown in diagram form in Figure 156.

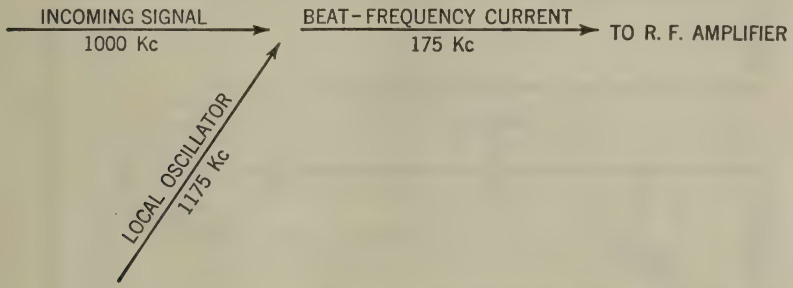


Figure 156. Diagram showing how the incoming signal mixes with the current produced by the local oscillator to produce the beat-frequency current.

The device used to generate the radio-frequency current which beats against the incoming signal is called the *local oscillator.*

To make this process clearer let us consider another example using the same tuning system having a natural frequency of 175 kc. Assume the incoming signal has a frequency of 800 kc. The local oscillator must now produce a radio-frequency current whose frequency is 975 kc. The beat-current frequency, again, is 175 kc., the frequency at which the radio-frequency transformers are set.

To produce a beat-frequency current of 175 kc., the local oscillator produces a radio-frequency current whose frequency is 175 kc. above that of the incoming signal. Since frequencies in the broadcast band lie between 550 kc. and 1,600 kc., the local oscillator for our set must be capable of producing radio-frequency currents whose frequencies are between 725 kc. (550 + 175) and 1,775 kc. (1,600 + 175). Further, we must connect together the control that selects the incoming signal with the control that regulates the local oscillator in such a way that the difference in frequency is always 175 kc.

Heterodyning is another name for the production of beats. It is from this word that we get the name of our new type radio set, the *superheterodyne receiver.*

188. Beat Production Occurs in the First Detector

As in the case of the tuned radio-frequency receiver, the incoming signal is selected by the tuning circuit consisting of the antenna coupler with a variable condenser across the secondary. The radio wave, a modulated carrier wave, causes a correspondingly modulated radio-frequency current to flow in the tuning circuit. This radio-frequency current is fed into the grid of an ordinary grid-leak–condenser detector. Without the local oscillator present, the modulated radio-frequency current would pass through this de-

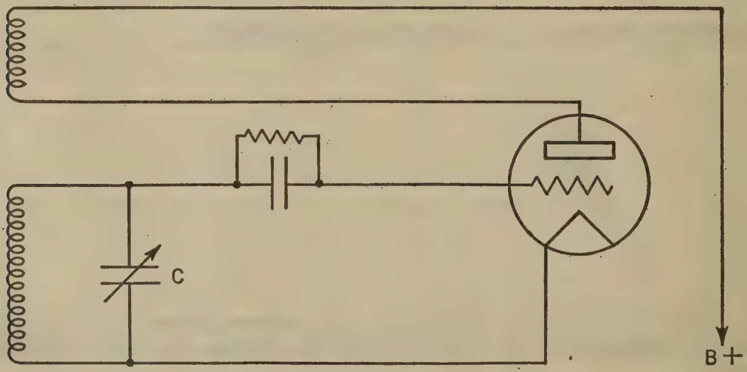


Figure 157. Circuit of the local oscillator. Note how it resembles the regenerative detector.

tector. The radio-frequency part or component would be eliminated and the modulating component (the audio-frequency component) would appear at the output of the detector tube.

This is another way of explaining detection and you now can see why the detector tube is sometimes called the *demodulator tube.*

But in the superheterodyne system, before detection occurs, the steady or unmodulated radio-frequency current from the local oscillator is mixed with the incoming signal. As a result, coming out of the plate of the detector tube is a new radio-frequency current whose frequency is the beat frequency and whose amplitudes are modulated in the same way as was the incoming signal. This new radio-frequency current is then fed into the radio-frequency amplifiers that are tuned to the same frequency.

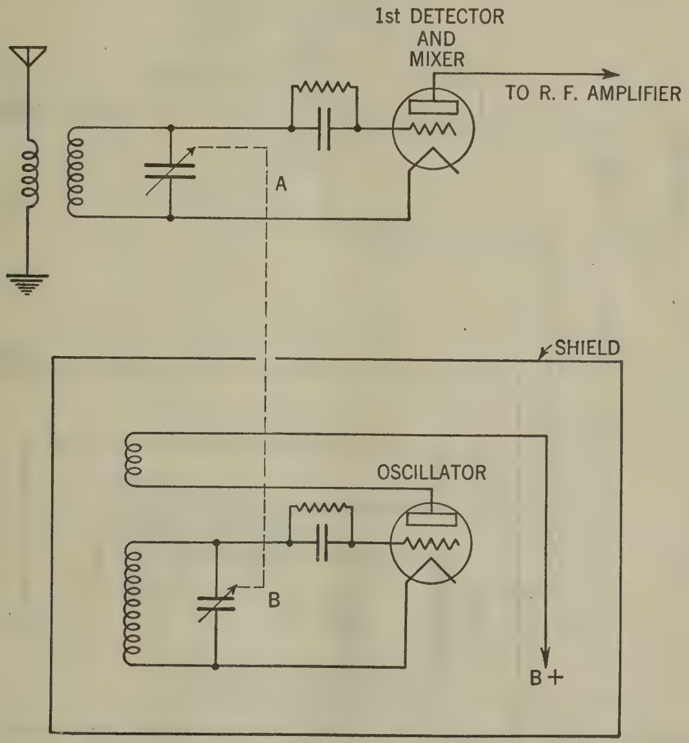


Figure 158. Condensers A and B are connected and turn together. (This ganging is shown by the dotted lines running from one variable condenser to the other.) Thus the natural frequencies of both tuned circuits are always a certain number of kilocycles apart (the beat frequency). Note that the local oscillator is shielded from the rest of the set.

Since the mixing of the two radio-frequency currents takes place in the detector tube, this tube is also called the *mixer tube.* It is called the *first detector tube* to distinguish it from the *second detector tube* which follows the radio-frequency amplifier tubes.

189. The Principle of the Local Oscillator

For the local oscillator we have to go back to the regenerative receiver (Chapter 16). Turn back to Figure 74. Current flowing in the plate circuit of the triode is fed back to the tuned circuit by means of a plate coil. This feed-back overcomes the resistance of the tuned circuit and the radio-frequency current flowing in that circuit (the oscillations of the electrons) is built up (see Figure 157).

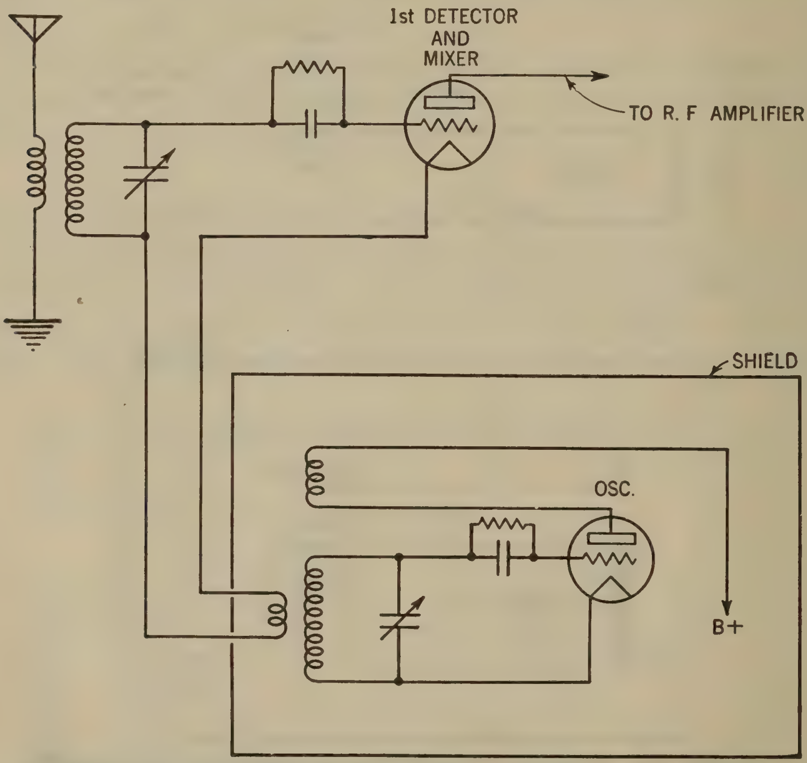


Figure 159. Circuit showing how current from the local oscillator is inductively coupled to the first detector and mixer circuit. The dotted lines showing that both variable condensers are connected to each other are omitted from this diagram for the sake of clarity.

The frequency of this radio-frequency current is determined by the electrical values of the inductance and variable condenser in the tuned circuit ($L \times C$). Changing the setting of the variable condenser will change the frequency of the current produced.

Here, then, is our local oscillator. By connecting the variable condenser of this oscillator with the variable condenser of the first detector circuit so that they turn together, and selecting the proper component parts (L and C), we are able to produce a radio-frequency current which at all times will be 175 kc. above the frequency of the incoming signal (see Figure 158).

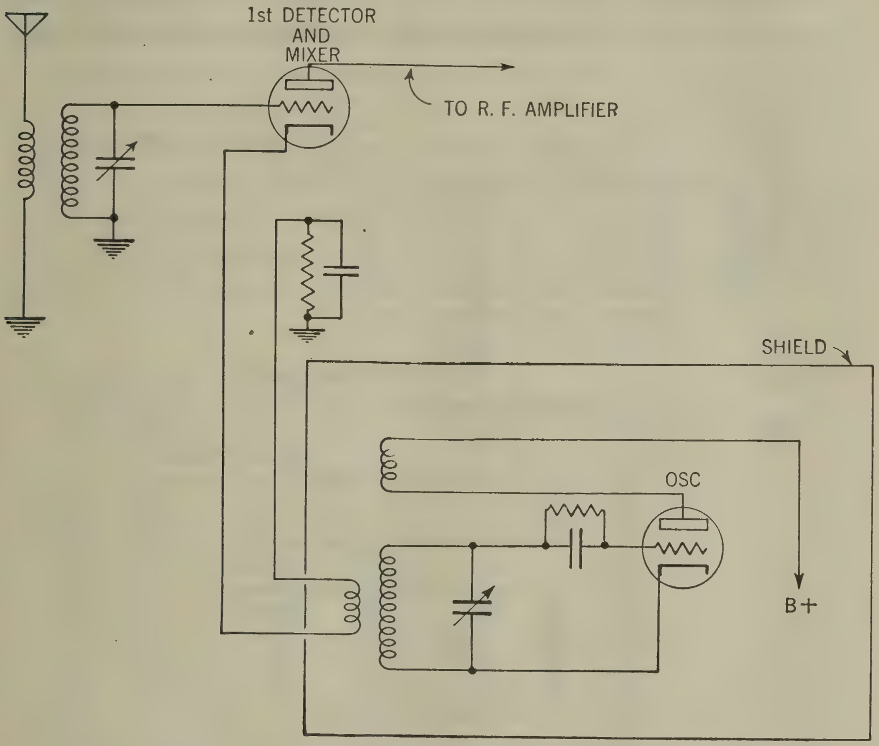


Figure 160. Circuit showing how current from the local oscillator is inductively coupled to the *cathode* of the first detector and mixer tube.

Note that 175 kc. is only taken as an example. Actually we can make this difference any frequency we wish, provided we have set our radio-frequency transformers to tune to that frequency.

190. Coupling the Oscillator to the First Detector

Several methods are used in feeding the radio-frequency current generated by the local oscillator into the mixing tube.

One such method is to make the circuits *inductive-coupled.* A coil of wire is placed near the tuned circuit of the oscillator. The radio-frequency current generated by the oscillator is passed on to this coil of wire by induction. The ends of the coil are connected in the grid circuit of the first detector and mixer tube as shown in Figure 159.

In this manner the radio-frequency current of the oscillator is mixed with the radio-frequency current flowing in the first detector and mixer circuit. The beat-frequency current results.

A variation of this method of coupling is to connect the ends of the coil in the cathode circuit of the detector and mixer tube as in Figure 160. When this method is used, it is customary to have the first detector hooked up as a resistor-biased detector.

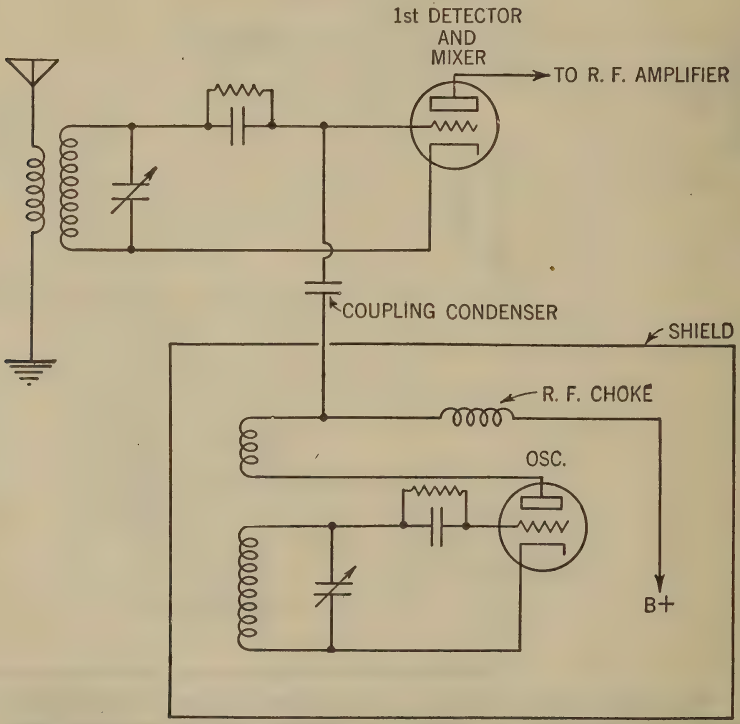


Figure 161. Circuit showing how a small fixed condenser is used to couple the current from the local oscillator to the grid of the first detector and mixer tube.

Another method is to make the circuits *capacity-coupled.* This time a small fixed condenser transfers the radio-frequency current from the oscillator to the grid of the first detector and mixer tube as shown in Figure 161. The radio-frequency choke in the plate circuit of the oscillator tube forces the radio-frequency current through the coupling condenser to the grid of the first detector tube.

With the invention of new types of tubes, a third method of coupling was invented. In this method the two circuits are coupled through the electrodes within the tube itself. We will discuss this electron coupling further in the chapter dealing with types of tubes (see Paragraph 215).

191. The Intermediate-frequency Amplifier

Coming out of the first detector and mixer tube is the beat-frequency current (175 kc. in our example). This is a radio-frequency current, since it lies well above the audio range of about 15 kc. per second. But it is lower than the broadcast frequencies which lie between 550 kc. and 1,600 kc. per second. We therefore call this beat frequency the *intermediate frequency* (abbreviated to I.F.). The tuned radio-frequency transformers which are set for this beat frequency are called intermediate-frequency transformers and the amplifier is called an *intermediate-frequency amplifier.*

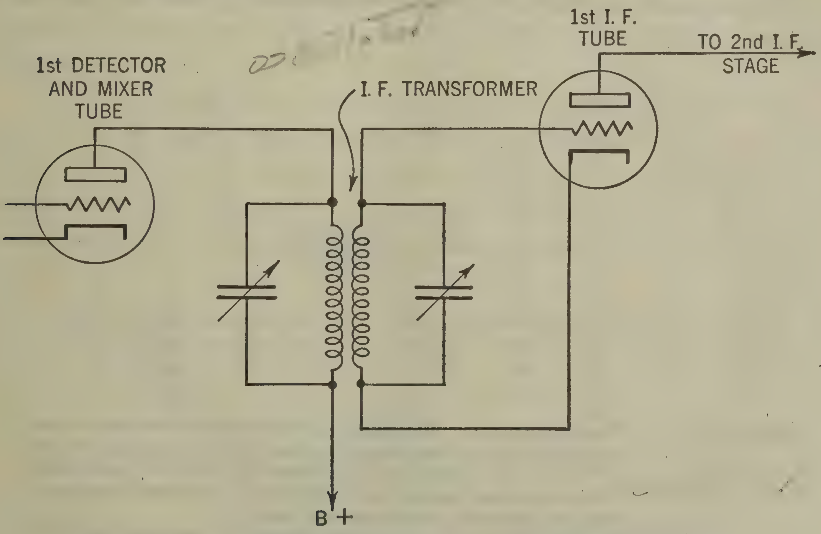


Figure 162. Circuit of the intermediate-frequency transformer.

The intermediate-frequency transformers differ from the regular radio-frequency transformers in a number of ways. Since they are tuned to a lower frequency, they have a greater number of turns of wire. Also, since they are to respond to only one frequency, the variable condenser is eliminated. Instead, we use a trimmer condenser adjusted to align the various tuned circuits.

Another difference is that the primary of the intermediate-frequency transformer, too, is usually tuned by means of a trimmer condenser. This arrangement, of course, increases the selectivity of the set. While it is quite possible to tune the primary of the ordinary radio-frequency transformer, the difficulty of ganging the extra variable condensers needed presents quite a problem and therefore this primary is not tuned. A diagram of the intermediate-frequency transformer used for an amplifier is shown in Figure 162.

As previously stated, the use of an intermediate-frequency transformer tuned to a fixed frequency means much greater sensitivity and selectivity. So sensitive is the superheterodyne set that it is quite possible to use a small loop aerial built inside the cabinet of the set itself instead of a long wire up on the roof.

The increase in selectivity may be shown by the tuning curves in Figure 163.

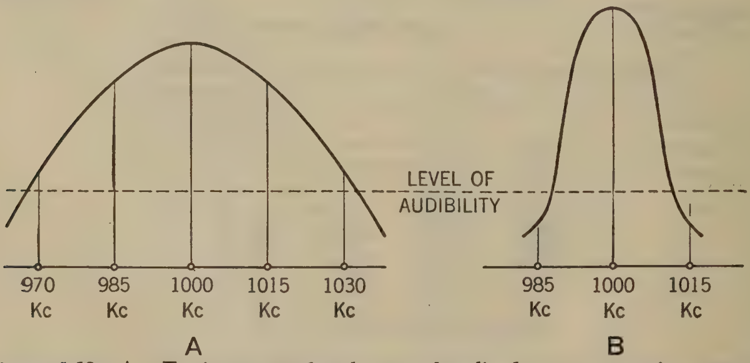


Figure 163. **A—Tuning curve for the tuned radio-frequency receiver tuned to 1,000 kc. Note that stations whose frequencies are 970 kc. and 1,030 kc. lie above the level of audibility. This condition means that they may be heard faintly in the background of the desired station.**
B—Tuning curve for the superheterodyne receiver tuned to 1,000 kc. Note that the unwanted stations fall below the level of audibility.

In Figure 163-A the curve indicates that when you tune in the 1,000-kc. station, the two stations whose frequencies lie 30 kc. on either side can be heard slightly. This tuning curve is typical for the tuned radio-frequency receiver.

Figure 163-B represents the tuning curve of the superheterodyne receiver. Here you will notice that stations 30 kc. away from the desired station (1,000 kc.) lie well below the level of audibility.

192. Can a Receiver Be Too Selective?

So selective is the superheterodyne that another problem may be presented. The set may be too selective! Here is what happens.

At the radio station, audio-frequency currents whose frequencies run up to 15 kc. per second are mixed with the steady radio-frequency carrier current generated by the transmitting set to produce the modulated radio-frequency current. Assume our broadcasting station has a carrier wave whose frequency is 1,000 kc. per second. The resulting beat current then would be 1,000 kc. minus 15 kc. or 985 kc. per second.

In discussing the production of beats we have omitted to tell you that when waves of two frequencies are mixed, not only is the beat frequency the *difference* between these two frequencies, but a beat frequency is also produced which is the *sum* of these two frequencies.

When we considered the beat-frequency current produced by mixing the incoming signal with the radio-frequency current generated by the local oscillator, we omitted the beat produced by adding the two frequencies because it lay well outside the range of our receiver. You will recall that we assumed an incoming signal whose frequency was 1,000 kc. per second. One beat frequency produced was 175 kc. The other beat frequency which we did not consider was 1,000 kc. plus 1,175 kc. or 2,175 kc. Since our intermediate-frequency transformers were tuned to 175 kc. the second beat could not be amplified.

But at the transmitting station the mixing of the 15-kc.-per-second audio current with the 1,000-kc.-per-second carrier current produces beat currents that have two different frequencies, one of 985 kc. and the other of 1,015 kc. per second. The radio station, therefore, broadcasts a wave whose frequency lies between 985 kc. and 1,015 kc. per second. The difference between the two frequencies (30 kc.) is called the *band width.*

Now if you will refer to Figure 163-B you will notice from the tuning curve for the superheterodyne receiver that when it is tuned to 1,000 kc. the extremes of the 30-kc. band width lie below the level of audibility. This means that some of the high notes will not be heard. We call this *cutting the side bands.*

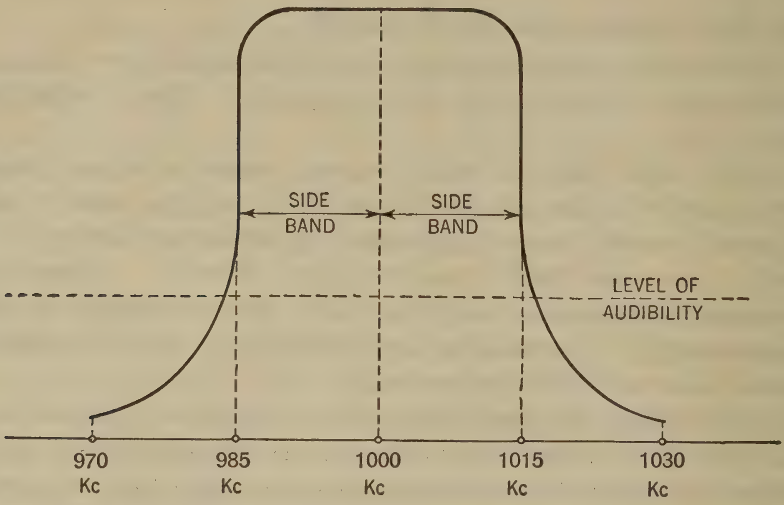


Figure 164. Ideal tuning curve for the superheterodyne receiver. Note that the side bands are fully received, while the unwanted stations are well below the level of audibility.

In other words, so great is the selectivity and so narrow is the tuning curve that the beat frequencies of 985 kc. and 1,015 kc. lie below the level of audibility. Thus the tone of the set will be too bass.

To remedy this defect we are compelled to reduce the selectivity of the set. The ideal condition would be to have the 985 kc. and 1,015 kc. on the tuning curve a little above the level of audibility as shown in Figure 164.

This broadening is accomplished by adjusting the trimmer condensers so that the set is slightly out of alignment. This adjustment broadens the tuning curve so as not to cut the side bands. While it is possible to judge this condition by ear, best results are accomplished by the use of special electrical instruments.

Except for the differences already noted, the intermediate-frequency amplifier is similar to the radio-frequency amplifier discussed in Chapter 23.

193. The Second Detector and Audio-frequency Amplification

The second detector following the intermediate-frequency amplifier is similar to the one used in the tuned radio-frequency set described in Chapter 23. A diode detector is customarily used, since the amount of amplification of the intermediate-frequency amplifier is great enough to overcome the loss of amplification that results from using a diode instead of a triode detector.

The automatic-volume-control system, the manual volume control, the tone control, and the audio amplifier are the same as those used in the tuned radio-frequency receiver.

194. Using a Radio-frequency Stage in Front of the First Detector

Sometimes a stage of ordinary radio-frequency amplification is placed in front of the first detector. While it is not necessary to increase the sensitivity or selectivity of the superheterodyne receiver (which is sensitive and selective enough without it), this radio-frequency stage serves two useful functions.

First of all, it serves to reduce the volume of any unwanted signals from powerful radio stations that may be in the vicinity of the receiver. If this stage were not present, this unwanted powerful signal would be impressed on the first detector and might cause some interference. While the radio-frequency stage may not completely eliminate this interfering station, it can reduce its signal strength to the point where the tuned circuit of the first detector can eliminate it completely.

195. Image Frequencies

But even more important is the fact that this radio-frequency stage eliminates what are called *image frequencies*. To get the idea of image frequency, assume that we are tuning to the 1,000-kc. station. Our oscillator produces a radio-frequency current whose frequency is 1,175 kc. A beat-frequency current of 175 kc. results, the same frequency to which our intermediate-frequency transformers are tuned.

Suppose, at the same time, there is a station whose frequency is 1,350 kc. This new signal will beat against the 1,175-kc. current produced by the oscillator and once again a beat frequency of

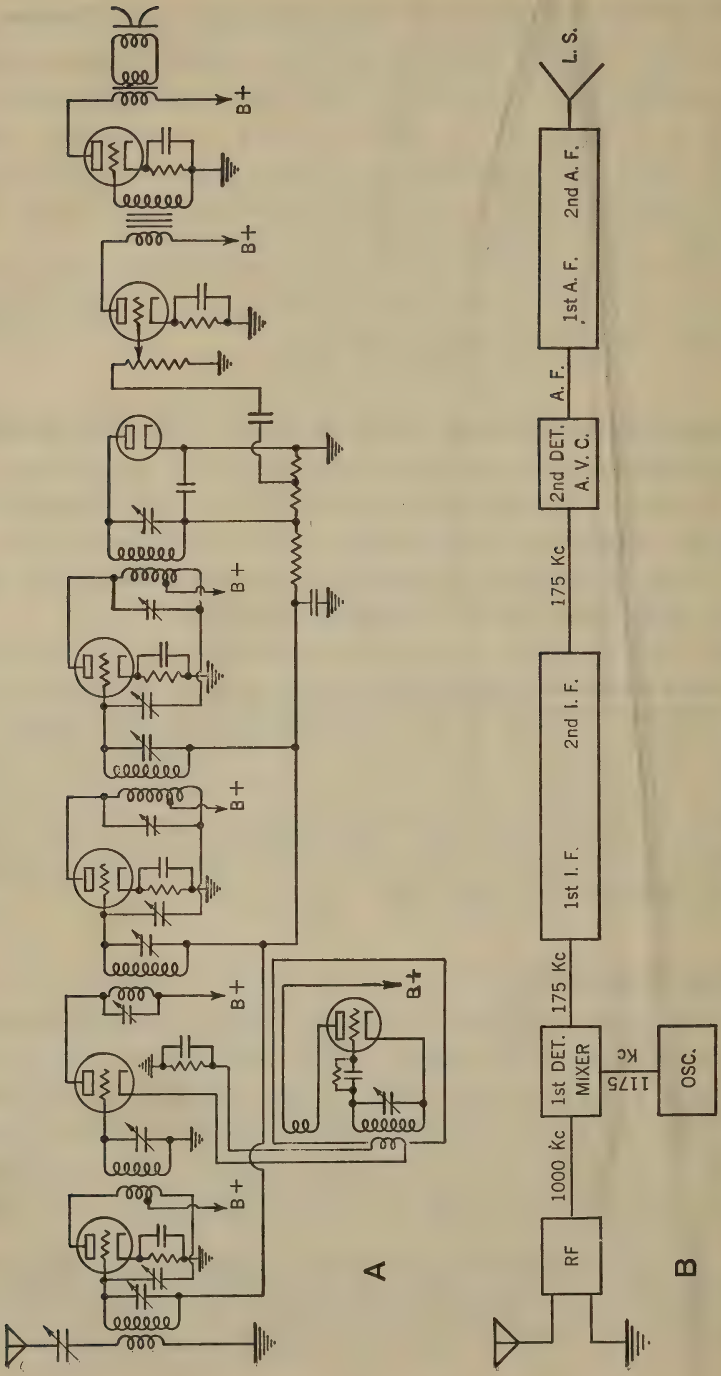


Figure 165. A—Circuit of the complete superheterodyne receiver.
B—Block diagram showing arrangement of the component parts.

175 kc. will result. This means that for every frequency produced by the oscillator there are *two* frequencies that will produce the desired beat frequency, one 175 kc. *above* the oscillator frequency and one 175 kc. *below* the oscillator frequency. Thus two stations may be passed on to the intermediate-frequency amplifier at the same time.

This second and unwanted frequency (1,350 kc.) is called the *image frequency.*

The stage of radio-frequency amplification eliminates the image frequency by tuning it out before it reaches the first detector.

Figure 165 shows the complete superheterodyne receiver.

SUMMARY

1. The tuned radio-frequency receiver cannot be tuned sharply and at the same time remain able to receive stations that have a wide range of frequencies.
2. The superheterodyne receiver provides a means of sharp tuning over a wide range by means of the principle of **beat notes.**
3. Beat is a phenomenon of the alternate reinforcement and neutralization of each other by waves of two frequencies. The number of beats produced by this reaction of two sets of waves is equal to the difference between their vibration frequencies.
4. The **first detector** in a superheterodyne receiver is a tube in which the radio waves from the aerial are mixed with the waves from a local oscillator.
5. The local oscillator is tuned so that the beat note produced by its wave mixed with an incoming radio wave will always be the fixed natural frequency of the intermediate-frequency amplifier.
6. The current from the first detector tube is a beat-frequency current that is of radio frequency, but lower than the broadcast frequencies.
7. The radio-frequency amplifiers are set for this beat frequency and such an amplifying system is called an **intermediate-frequency amplifier.**
8. The superheterodyne receiver is very sensitive and tunes so sharply that if it is to respond to the **side bands** trimmer condensers must be used to keep the set a trifle **out of alignment.**

GLOSSARY

Band Width: The range of frequencies of the radio wave sent out by a transmitting station.

Beats: The result of combining two waves of similar nature but of different frequencies. Thus we must combine two sound waves or two alternating currents of different frequencies. The result, in the case of the sound waves, will be a new sound wave whose amplitudes vary at a frequency equal to either the difference between the two frequencies or the sum of the two frequencies. In the case of the alternating currents, the amplitudes of the resulting current will vary in the same manner.

Capacitive Coupling: A method of coupling electrical energy from one circuit to another through a condenser.

Heterodyning: The production of beat notes or currents by mixing two waves or two alternating currents of different frequencies.

Image Frequency: A frequency that is as much above the oscillator frequency as the desired station frequency is below that of the oscillator. Thus the signals from two different stations may be fed into the intermediate-frequency amplifier at the same time.

Inductive Coupling: A method of coupling electrical energy from one circuit to another by mutual induction.

Intermediate Frequency: The frequency that lies between the radio frequency of the received signal and audio frequency. It results from heterodyning two different radio frequencies.

Intermediate-frequency (I.F.) Transformer: A transformer tuned so that its natural frequency falls within the intermediate-frequency range.

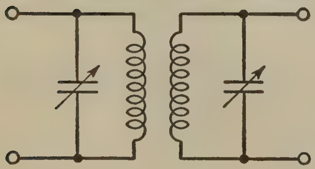
Local Oscillator: A generator of radio-frequency currents in a superheterodyne receiver.

Mixer Tube: A tube in the superheterodyne receiver in which the incoming signal current is mixed with the radio-frequency current from the local oscillator to produce the intermediate-frequency current.

Side Band: The band of frequencies on either side of the fundamental carrier frequency, simultaneously transmitted with it by the broadcast station.

Superheterodyne Receiver: A radio receiver using the heterodyne principle.

SYMBOLS



Intermediate-frequency transformer.

QUESTIONS AND PROBLEMS

1. List some of the weaknesses of a tuned radio-frequency receiver.
2. What is meant by a beat note?
3. What is the function of the local oscillator in the superheterodyne receiver?

4. Describe what occurs in the first detector of a superheterodyne receiver.
5. Describe the operation of the local oscillator.
6. How is the local oscillator coupled to the first detector?
7. What advantage lies in the use of intermediate-frequency transformers in the superheterodyne receiver?
8. What is meant by intermediate-frequency?
9. To what frequency are intermediate-frequency transformers tuned?
10. What are the advantages of a superheterodyne receiver over other types of receivers studied?
11. What happens to the beat frequency in a superheterodyne receiver which is the sum of the two mixed frequencies?
12. What is meant by band width?
13. What is meant by "cutting the side bands"?
14. How is the cutting of side bands in the superheterodyne eliminated?
15. What type of detector is commonly used in a superheterodyne receiver?
16. Why is a radio-frequency amplifier stage placed before the mixer in a superheterodyne receiver?
17. What is image frequency?
18. Draw a complete superheterodyne receiver, with automatic volume control.

CHAPTER 27

Types of Vacuum Tubes

Problem 1: *To review the functions of the diode and triode.*
Problem 2: *What are some methods of adapting single radio tubes to many purposes?*
Problem 3: *What are some trade numbers of certain special tubes?*

As you have learned, it is possible to have radio without vacuum tubes. Nevertheless, the radio tube has changed what was a scientific toy into one of the world's greatest industries. The vacuum tube has greatly influenced our present civilization.

196. General Principles of Vacuum Tubes

The basic principles of the vacuum tube are nevertheless extremely simple. Let us study the vacuum tube more attentively. Surrounded by a vacuum, the heated filament or cathode emits a stream of electrons which form a one-way path to a positively charged plate or anode. The more the cathode is heated, the more electrons it sends out. The more positive the charge on the plate, the more of these electrons it attracts. (It should be remembered that these two statements hold true between certain limits. If you heat the filament too much it will burn up. After a certain limit is reached, placing a higher positive charge on the plate will attract no more electrons.) (Chap. 37, Vol. II.)

In some tubes, the cathode is the filament itself. This filament may be a thin wire, as in type 01A tubes. Or else it may be a heavy metal ribbon coated with certain chemicals to permit it to shoot off more electrons, as in the type 26 tubes.

In tubes of other types, the filament is merely an electric stove or heater, heating up the relatively heavy metal tube or sleeve that fits over it. This tube or sleeve is the cathode, which when heated sufficiently emits the electrons that find their way to the plate. The type 27 tube is an example of this class.

Tubes having thin filaments usually are heated by direct current. Alternating current is generally used to heat the heavy ribbon filaments. The separate-heater types of tubes may be heated either by direct or alternating current.

197. Special Voltages

In practice, the tube manufacturers design the filaments and heaters of their tubes to operate at certain voltages. Thus the filament of the 01A tube operates at the 5 volts obtained from a storage battery. For use in portable receiving sets, the 1H5-G type of tube has a filament which operates from the 1½ volts furnished by a single dry cell.

Other types of tubes require different voltages. The type 45 uses 2½ volts on its filament. The heater of the 117Z6 tube uses 110 volts. There are many other types of tubes using other voltages. But the voltage at which the filament or heater of the tube operates does not determine the character or nature of the tube.

198. The Diode

Simplest of all vacuum tubes is the two-element tube or *diode.* These two elements consist of an emitter of electrons (either a filament or separately heated cathode), and a plate. These two elements are sealed inside a glass bulb from which all air has been evacuated.

As described in Chapter 14, the diode makes for an excellent detector. It is also used as a rectifier, changing alternating current into direct current to be used by the B eliminator (Chapter 18 and by the automatic volume-control circuit, Chapter 24).

The I-V and 12Z3 types of tubes are typical diodes. Sometimes two diodes are sealed into one envelope to make a *full-wave rectifier.* Examples of this type of tube are the 80, 5Z3 and 6H6 tubes.

199. The Triode

When Dr. DeForest placed a third element, the grid, between the cathode and plate of the diode, he introduced the magical word *amplification.* As already explained in Chapter 15, a small voltage placed upon the grid of the tube controls the stream of electrons rushing from the cathode to the plate. This electron stream in turn controls the comparatively large plate current. Since this large plate current varies in step with the small voltage placed upon the grid, amplification results.

The amplifying quality of a tube is called the *amplification factor,* which appears in electrical formulas as the Greek letter *mu* (μ). Here is what it means.

In Figure 166, we have a triode with a meter in the plate circuit.

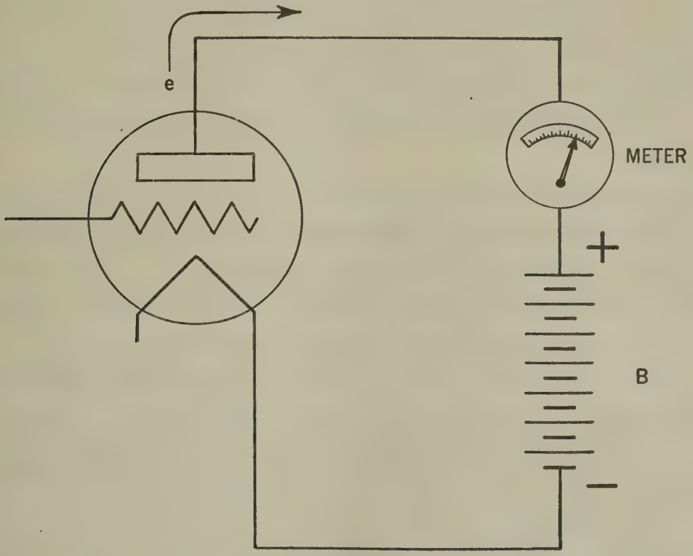


Figure 166. Meter connected in the plate circuit of the triode to show the flow of electrons.

Electrons flowing from the filament are attracted to the positively charged plate and flow on through the meter, which registers their flow. Assume that you now increase the B battery by 35 volts. The greater positive charge on the plate attracts more electrons and the meter now shows that more are flowing through it.

At this point a negative charge is placed on the grid. This will cut down the flow of electrons to the plate and fewer electrons will flow through the meter. Assume that when you have placed a negative charge of 5 volts on the grid, the meter will show the same number of electrons flowing through it as before the plate charge was raised by 35 volts. This means that 5 volts applied to the grid will have the same effect as 35 volts (of opposite charge) applied to the plate of the tube.

The amplification factor or *mu* (μ) of this tube is therefore 35 divided by 5, namely 7.

200. What Determines The Amplification Factor of a Triode?

The amplification factor of a triode is determined by the mechanical construction of the tube. The nearer the grid is to the cathode, the greater is its effect on the stream of electrons flowing to the plate and the greater is the *mu* or amplification factor of the tube. Also, the finer the mesh of the grid, the greater the effect of a charge upon the grid and again the greater the *mu*. If the open spaces in the grid are wide, the electrons are able to rush to the plate without being very much affected by the grid charge. This condition accordingly makes for a smaller amplification factor.

In the triode, we are unable to use a grid of very fine mesh because the consequently larger area of the grid would greatly increase the internal grid-to-plate capacitance. This would increase the feedback and cause the receiver to oscillate, resulting in distortion (see Chapter 23). It is partly because of this fact that triodes have a relatively small amplification factor. The type 27 tube has a *mu* of 9 and type 01A a *mu* of 8.

There is another factor that limits the *mu* of the triode. The electrons shot off by the cathode have a negative charge. Thus they tend to repel each other and many more are shot out than actually reach the plate. Of these electrons that do not reach the plate, a large number accumulate and fill the space around the cathode inside the envelope of the tube. This accumulation charges the space around the cathode, and is therefore called the *space charge*.

Any new electrons shot off by the cathode must fight their way through this space charge to reach the plate. It is estimated that about 85 per cent of the positive charge on the plate of the tube is used to overcome the repelling effect of the space charge, leaving about 15 per cent for amplification purposes.

The space charge, surrounding the grid, also interferes with its action and thus further reduces the *mu* of the tube.

201. Amplification Outside the Tubes

In addition to the amplification furnished by the tube, there is the amplification due to the step-up action of the transformer. Figure 167 shows what is meant by a *stage of amplification*.

We may calculate the amplification of this stage by dividing the output voltage by the input voltage. Thus, if the output voltage is 50 volts and the input voltage is 5 volts, the amplification furnished by this stage is 50 divided by 5, or 10.

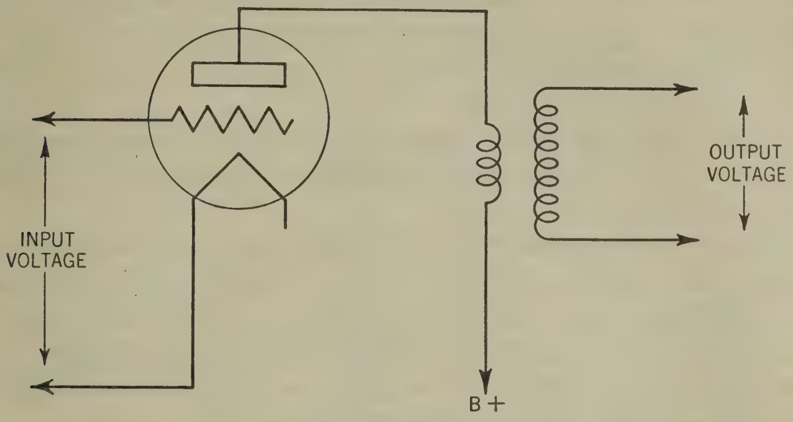


Figure 167. Diagram showing what is meant by a stage of amplification.

202. The Power Tube

We must remember that the radio tube is a voltage-operated device; that is, the varying voltage which is fed into the grid controls the current flowing in the plate circuit of the tube. It becomes the function, then, of each stage of amplification to amplify the variations of voltage fed into the grid. Each stage has this function, except the final audio-frequency stage, whose function it is to supply the fluctuating current or power that operates the loudspeaker.

Electrons, shot out by the cathode and attracted to the plate, circulate through the voice coil of the loudspeaker which is either in the plate circuit or else coupled to the plate circuit by means of an output transformer (see Chapter 22). The frequency of sound coming from the speaker depends upon the frequency of variations in the electron stream. The volume or loudness of this sound depends upon the amplitude of these variations. Thus, to operate our speaker at a loud level, we need a dense stream of electrons flowing in the plate circuit. Therefore, the cathode must be capable of emitting a large quantity of electrons and the tube must be able to pass them on to the plate.

It is for this reason that the last stage of audio-frequency amplification is called the *power stage* and the tube that operates this stage is called the *power tube.*

If the power tube is of the filament type, this filament is usually made quite heavy and rugged and is coated with chemicals that increase the electronic emission. A power tube may also contain a large number of filaments connected together to give the same effect as one heavy filament. Tubes such as the type 45 and the type 2A3 are examples.

Where the tubes have separately heated cathodes, these cathodes are large and are able to emit a large number of electrons. The 6AC5-G is such a tube.

When the electrons strike the plate, they are traveling with considerable speed and the force of the impact heats up the plate. It is for this reason that the plate of the power tube must be larger and more rugged than for the other types of tubes. It is usually coated with graphite to give it a black surface so that it may radiate away its heat more effectively.

203. Power Tubes Have a Small Amplification Factor

While the grid of the power tube must control the flow of electrons from the cathode to the plate, it must not block off too many of these electrons that are needed so badly in the plate circuit. For this reason, the grid of the power tube has an open mesh and is not placed so close to the cathode as in the case of other types of amplifier tubes.

This construction in turn reduces the amplification factor of the power tube. Thus the *mu* of the type 2A3 tube is only 4.2 and that of the type 45 tube 3.5. Power tubes of the triode class generally have a low amplification factor.

Since the grid of the power tube is of open mesh and relatively far from the cathode, changes in the grid voltage do not affect the flow of electrons in the plate circuit as much as if the grid were of finer mesh and closer to the cathode. In order to create a certain variation in the plate current, therefore, any change in the charge on the grid of the power tube needs to be greater than the change needed by another type of amplifier tube. We say that power tubes of the triode class have low *power sensitivity.*

Because this greater *grid-voltage variation* or *swing* is necessary to operate the power tube, it is important that most of the amplification of the signal should occur before the current is fed into the power tube. For this reason it is customary to have a stage of audio-frequency amplification between the detector and power stage.

204. Two Power Tubes in Parallel

Sometimes the power required for the loudspeaker is too great for a single tube to handle. In such cases we can connect two identical power tubes in *parallel.* The grid of one tube is connected to the grid of the other, the plate to the other plate, and the cathode to the other cathode (Figure 168).

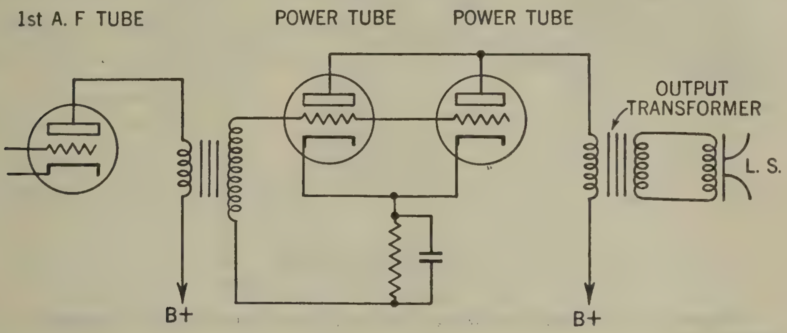


Figure 168. Circuit showing how two power tubes are connected in parallel to handle greater power.

The voltage placed upon the grids of two tubes in parallel is the same as that on the grid of one tube. But because two cathodes are emitting electrons, the current set flowing in the plate circuit of the tubes is twice as large. Thus from two tubes we can get nearly twice the power output that a single tube can deliver to operate the loudspeaker. It is quite obvious that three or more tubes may be connected in parallel. It is not practical, however, to use more than two tubes for ordinary purposes.

205. The Push-pull System for Power Tubes

Another method of multiplying the output of the power tube is to connect two of them in *push-pull.* Figure 169 shows this circuit.

You will notice that the secondary winding of the input transformer is center-tapped. Each end of this winding goes to the grid of one of the power tubes. The center tap is connected to the grid-bias resistor which in turn is connected to both cathodes.

Thus a negative bias is placed on the grids of the tubes (see Chapter 20).

The primary or the output transformer also is center-tapped. Each end of that winding goes to one of the plates while the B+ terminal is connected to the center tap. Here is how this hookup works.

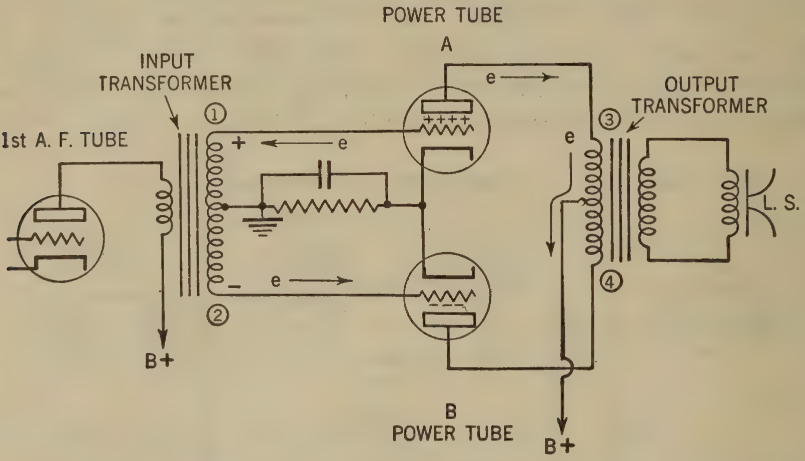


Figure 169. Circuit showing how two power tubes are connected in push-pull.

The fluctuating current in the plate circuit of the first audio-frequency tube sets up an alternating voltage across the secondary of the input transformer. Assume an instant when point 1 of the secondary is positive; point 2 then is negative. In this situation a positive charge is placed upon the grid of tube A and a negative charge upon the grid of tube B.

In tube A, the electrons shot out by the cathode are sped on to the plate and flow to point 3 of the primary of the output transformer. They then flow through the coils of the primary to the center tap and out to the positive post of the B supply.

As the current flows through the upper half of the primary of the output transformer, a magnetic field is built up. This field, cutting across the secondary of the output transformer, sets up an electrical pressure that sends current flowing through the voice coil of the loudspeaker (see Chapter 22).

Now let us see what is happening in tube B. The negative charge on the grid cuts off the flow of electrons to the plate. Thus the plate current is reduced and the current flowing through the lower half of the primary of the output transformer falls off. This falling-off causes the magnetic field to collapse.

But a collapsing magnetic field, cutting across a conductor, sets up an electrical pressure across that conductor just as an expanding magnetic field does. Thus a second electrical pressure is set up across the secondary of the output transformer and, as a result, a much greater current flows through the voice coil of the loudspeaker.

Note that while the current flowing in one tube is increasing, the current in the other tube is diminishing. Also notice that we need twice the grid voltage that is needed to operate a single tube in order to operate a pair of tubes in push-pull. Power tubes connected in push-pull produce very little distortion of the signal.

206. The Tetrode

It was stated, earlier in this chapter, that the triode has a low amplification factor because:

1. We cannot use a fine-mesh grid since this causes too great a grid-to-plate capacitance and thus too much feedback.
2. The space charge within the tube wastes about 85 per cent of the positive charge on the plate.

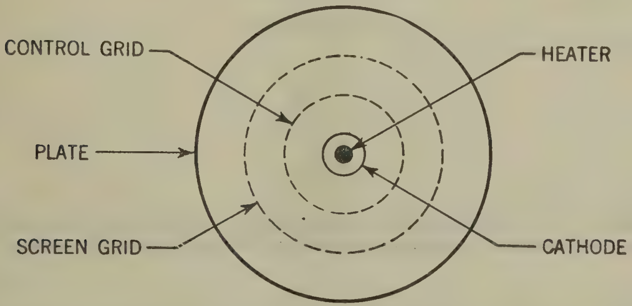


Figure 170. Looking down on the top of a screen-grid tube showing the arrangement of the electrodes.

To overcome these difficulties, in some tubes a second grid is placed between the original grid, now called the *control grid,* and the plate. This new grid is called the *screen grid.*

The screen grid is connected to the B+ terminal, but a dropping resistor reduces the positive charge on it to a value considerably less than that on the plate. Thus if a positive charge of 250 volts is placed on the plate, 100 is placed on the screen grid.

207. Action of the Screen Grid in the Tetrode

This new grid acts as a screen between the plates of the condenser formed inside the tube by the control grid and plate, and thus reduces the internal capacitance of the tube. Thus the amount of feedback is cut down to almost zero and the evil of oscillation is eliminated.

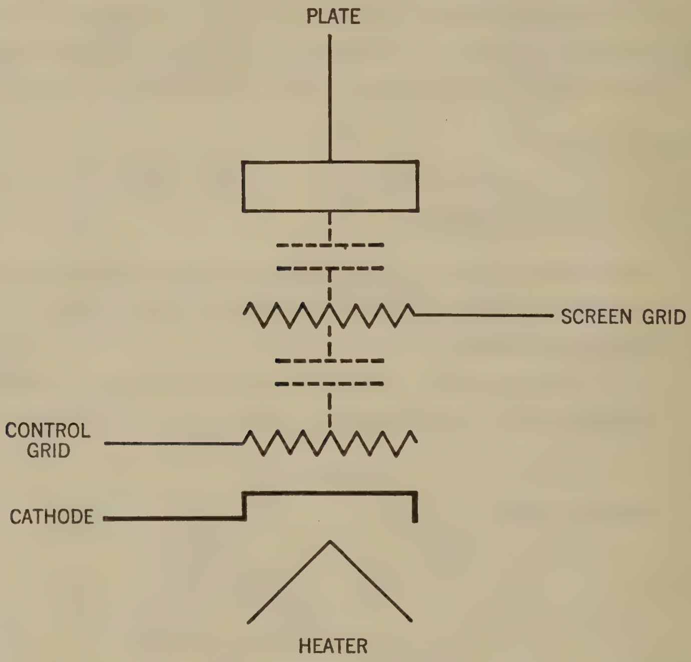


Figure 171. Arrangement of electrodes within the screen-grid tube showing the internal capacitance between the grids and the plate.

So while the 01A tube has a grid-to-plate capacitance of 8 $\mu\mu$ fd., the type 24A screen-grid tube has a grid-to-plate capacitance about .007 $\mu\mu$fd.

As a result, we can now use a closely meshed control grid and this structure gives us a much greater amplification factor.

Another result of introducing the positively charged screen grid is the dissipation of the space charge. The electron cloud which otherwise fills the inside of the tube is attracted to the screen grid. Some of the electrons hit the wires of this grid and go off to the positive post of the B supply. But most of them go through the openings and travel on to the plate, which has a higher positive charge. This electron stream gives a greater plate current and a much greater amplification factor for the tube, because now any new electrons emitted by the cathode need not dissipate themselves battling the repellent effect of the space charge.

We can fully appreciate the effect of the screen grid when we compare the amplification factor of 8 for a triode such as the type 01A with that of 400 for the type 24A screen-grid tube. While losses in the circuit may cut the real *mu* down to 40 or 50, nevertheless you can readily see the advantage of the screen-grid tube.

208. The Screen Grid Is the Fourth Electrode

Because the screen grid forms the fourth electrode in the tube, we call this new type of tube a *tetrode,* meaning four electrodes. In the type 24A tube the control grid is connected to a cap on the top of the tube. Another screen is usually placed around the outside of the plate and is connected to the inner screen grid. This screen tends to shield the entire tube from external disturbances.

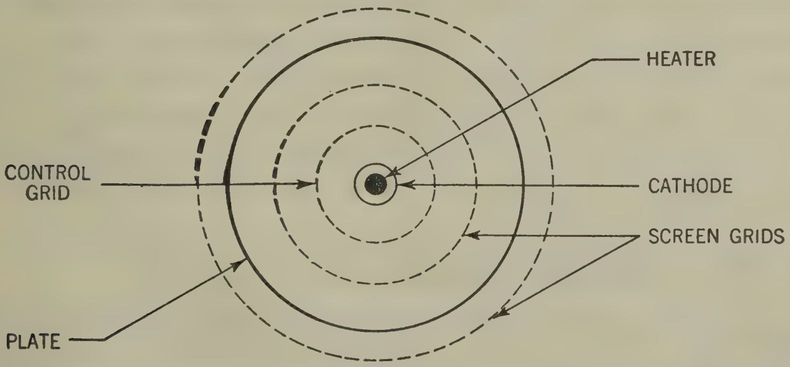


Figure 172. Looking down on the screen-grid tube. Note the screen grid around the outside of the plate.

Because of the low grid-to-plate capacitance of the tetrode, there is no danger of oscillations being set up as the result of feedback. This condition makes it unnecessary to neutralize the radio-frequency and intermediate-frequency stages of amplification. Figure 173 shows the circuit of a typical radio-frequency stage using the tetrode. Note that the screen grid is by-passed to ground by a .001-μfd. condenser to eliminate any stray radio-frequency currents.

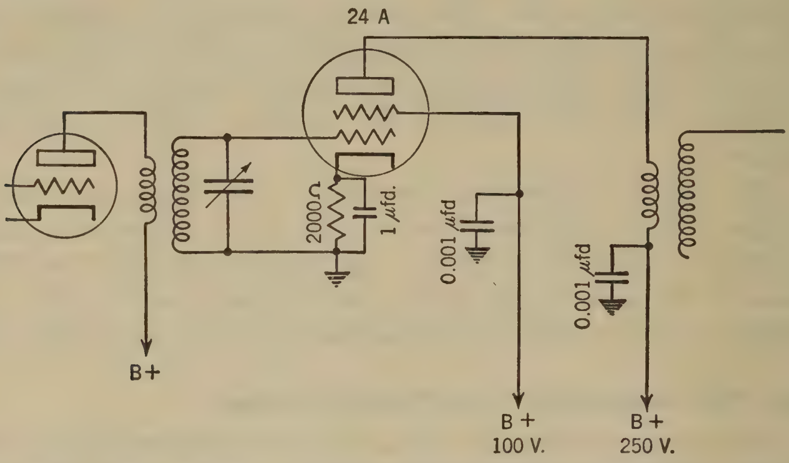


Figure 173. Circuit of a stage of radio-frequency amplification using the 24A type of screen-grid tube.

Since the positive charge on the screen grid dissipates the space charge on the tube, changing this positive charge will affect the space charge in the tube and thus the amplification factor. Because of this, the automatic volume-control voltage may be fed into the screen grid and thus control the amplification of the receiver. In practice, however, automatic volume control is usually maintained by means of variations of the grid bias as explained in Chapter 24.

209. Other Uses of the Tetrode

The tetrode may be used as an audio-frequency amplifier although our study of the power tube shows why the screen-grid tube is not suitable as an output tube.

The screen-grid tube may be also used as a detector as shown in Figure 174.

Figure 174-A shows the tetrode hooked up as a grid-leak–condenser detector while Figure 174-B shows the circuit of a grid-bias detector. The 50,000-ohm potentiometer controls the positive charge placed on the screen grid and thus acts as a volume control by varying the amplification factor of the tube.

210. Variable-*mu* Tubes

The control grid of the screen-grid tube has a very fine mesh. This means that as the electrons stream through the spaces between the wires, they are forced to pass quite close to those wires. A very small charge upon the wires of the grid, then, has a great effect on the electron stream flowing to the plate of the tube. The screen-grid tube is ideal for the purpose of delivering a large voltage from a small one.

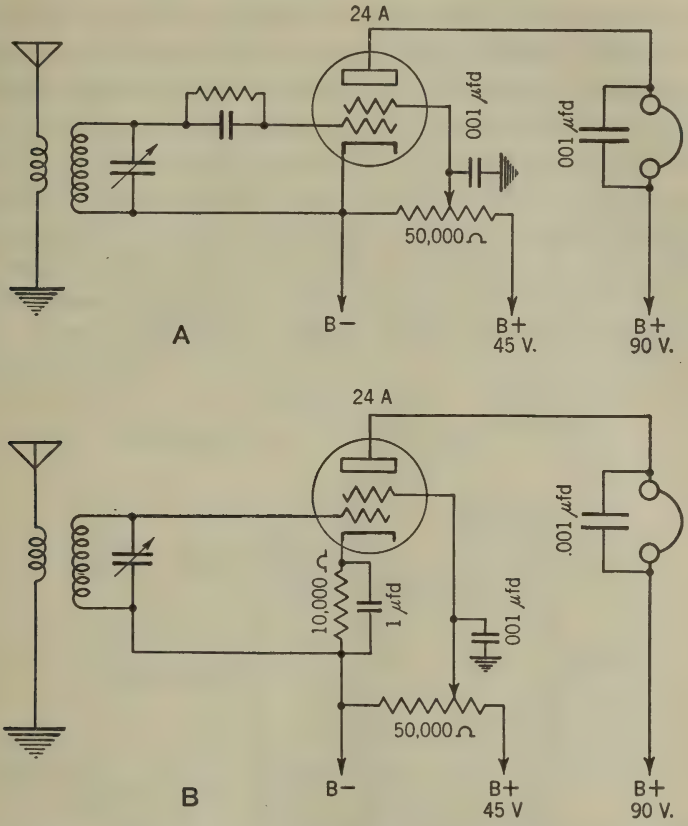


Figure 174. A—Circuit of a tetrode used as a grid-leak–condenser detector. B—Circuit of a tetrode used as a grid-bias detector.

The very construction that makes this tube so suitable for handling small voltages prevents it from handling high voltages. It does not require a great negative charge on the control grid to stop entirely the flow of electrons to the plate. Thus, if a large alternating voltage should be fed into the grid, the positive half of the cycle would go through well enough, but most of the negative half cycle would be blocked out and detection or rectification would result.

If the screen-grid tube is used as a radio-frequency amplifier in a set which is located near a powerful station, the strong signal from that station will cause the automatic volume-control system to send a large negative bias to the control grid of the tetrode. This bias plus the negative half cycle of the incoming signal will cut off the flow of electrons to the plate and the radio-frequency tube will act as a grid-bias detector (see Chapter 15). This phenomenon causes a form of distortion called *cross modulation.*

This interference does not occur if the wires of the control grid are widely spaced. Charges on the grid have little effect on the electrons as they stream through the wide open spaces. But, of course, the amplification factor of the tube is much less.

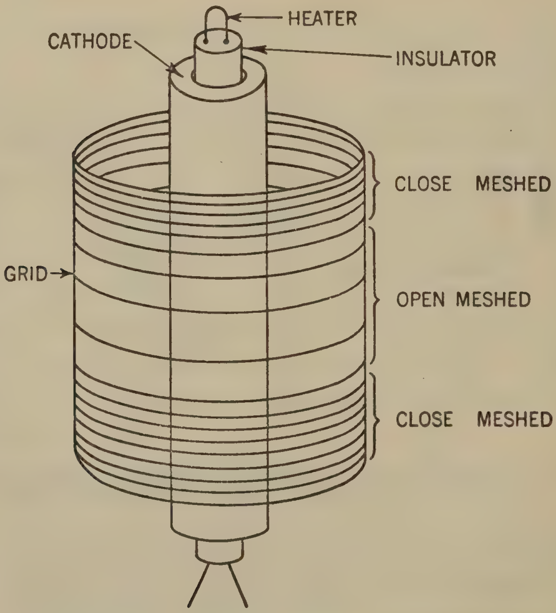


Figure 175. Diagram showing the construction of the control grid of a variable-*mu* tube.

The ideal condition, then, would be to hook up one tube with a close-meshed control grid and one with an open-meshed control grid in such a way that weak signals would travel through the close-meshed tube where they would be greatly amplified and the strong signals, that did not need so much amplification, would travel through the open-meshed tube where they could not cause distortion.

This ideal was achieved in one tube by constructing a control grid that is close-meshed at the ends and open-meshed in the center.

When a weak signal comes in, the automatic volume-control sends little negative bias to the control grid of the radio-frequency tube and this tube then acts as a conventional screen-grid amplifier. When a loud signal comes in the negative bias of the tube is increased. This increased bias means that the electrons cannot get through the fine mesh at both ends of the control grid. But in the center, where the mesh is open, the electrons can get through and the tube now acts as a low-*mu* amplifier.

Such a tube is called a *variable-mu tube* or *supercontrol radio-frequency amplifier.* One example of such a tube is the type 35.

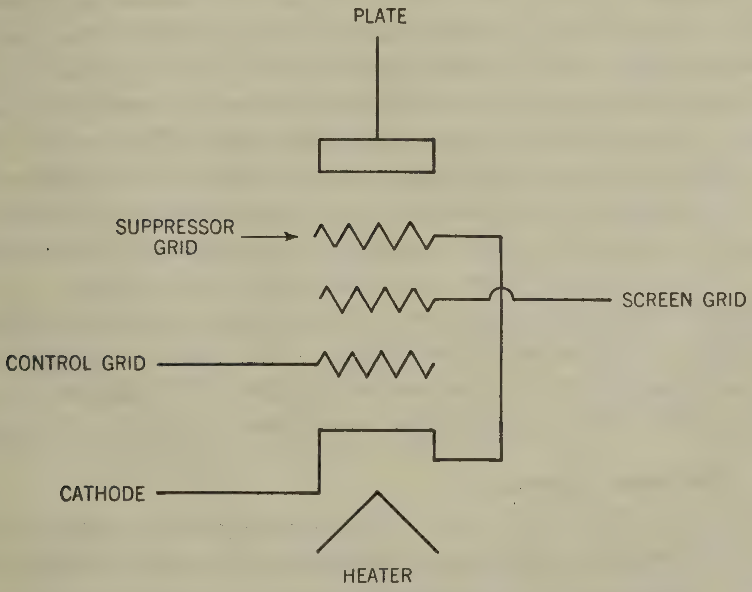


Figure 176. Arrangement of electrodes in the pentode tube.

211. The Radio-frequency Pentode

Although the screen-grid tube makes an excellent radio-frequency amplifier, it suffers from one defect. Because the space charge has been overcome and also because of the added pull of the positive charge on the screen grid, electrons leaving the cathode attain a speed as great as 20,000 miles per second and strike the plate with great force.

The force of impact is great enough to knock some electrons off the plate. This phenomenon is called *secondary emission.* These electrons fly about in space and either are pulled back by the positive charge of the plate or else are attracted to the positively charged screen grid nearby. The electrons lost to the screen grid reduce the supply left for the plate circuit of the tube and amplification falls off.

To remedy this defect a third grid is placed between the screen grid and the plate. This new grid is connected to the filament or cathode of the tube.

Since it is connected to the cathode, this new grid has no charge on it and therefore will have no effect upon electrons passing through it on their way to the plate. But as compared to the positive charge on the plate, this new grid is negative. Therefore any electrons knocked off from the plate by secondary emission will be turned back by this grid to the plate where they belong. Because of this fact, the new grid is called the *suppressor grid.*

Because they have five electrodes (cathode, three grids, and a plate), tubes of this type are called *pentodes.* They make excellent radio-frequency and intermediate-frequency amplifiers because they have the sensitivity and high amplification factor of the screen-grid tubes plus the ability to suppress secondary emission. They are also known as *radio-frequency pentodes.*

The 34 tube is of this type. The suppressor grid is connected internally to the center of the filament. Sometimes the suppressor grid is led out to one of the base connections. We then must connect it to the cathode externally. The type 58 tube is an example.

212. The Power Pentode

Like the screen-grid tube, the radio-frequency pentode is not suited for use as a power tube. Let us see if we can design a good power tube.

First of all, it must be capable of handling a good deal of power. Hence the cathode must be a very strong emitter of electrons. These electrons must find their way to the plate quite readily. Hence we must have an open-meshed grid. The plate must be large and rugged to withstand the bombardment of electrons.

So far we have described our old friend, the triode power tube.

Now, let us see if we can step up its amplification factor. We cannot make the grid more fine-meshed because doing so would cut down the flow of needed electrons and thus reduce our power. But we can eliminate the space charge that uses up about 85 per cent of the positive charge on the plate. So between the control grid and the plate we place a positively charged screen grid and the amplification factor shoots up.

But not so fast. We are dealing here with heavy streams of electrons. Without the restraining effect of the space charge, the electrons hit the plate with tremendous impact, knocking off clouds of electrons. A large number of these electrons are attracted to the positively charged screen grid and down goes our amplification factor.

Well, let us put in a suppressor grid between the screen grid and the plate. Connect this suppressor grid to the cathode, and the electrons knocked off by the impact are forced back to the plate and up goes the amplification factor.

This tube is called a *power pentode* and one example is the type 47. Compare its amplification factor of 150 with that of the triode type 45, whose amplification factor is 3.5. Because a small grid voltage can control a large amount of power in its plate circuit, the power pentode may work directly from the detector without any need for an intervening stage of audio-frequency amplification.

Like the triode power tube, the power pentode can be connected in parallel and in push-pull circuits to get greater power output.

Although they are both pentodes, the radio-frequency pentode and the power pentode are not interchangeable. In reality, they are tubes of two different types.

213. The Beam Power Tube

Although it has only four electrodes, the *beam power tube* is in reality a variation of the power pentode. Here is how it works.

Electrons, shot off from the cathode, pass between the wires of the control grid and the positively charged screen grid. This screen grid has a higher positive charge than the plate. This charge acts as a brake, slowing down the electrons in their flight to the plate. Deflector plates, connected to the cathode and therefore having the same zero charge, concentrate these electrons into a cloud or beam, moving slowly towards the plate. Any electrons knocked off by secondary emission are repelled back to the plate by this beam of electrons. Thus it can be seen that the space charge created by the beam of electrons acts just as the suppressor grid acts to overcome the effects of secondary emissions. Examine the diagram in Figure 177.

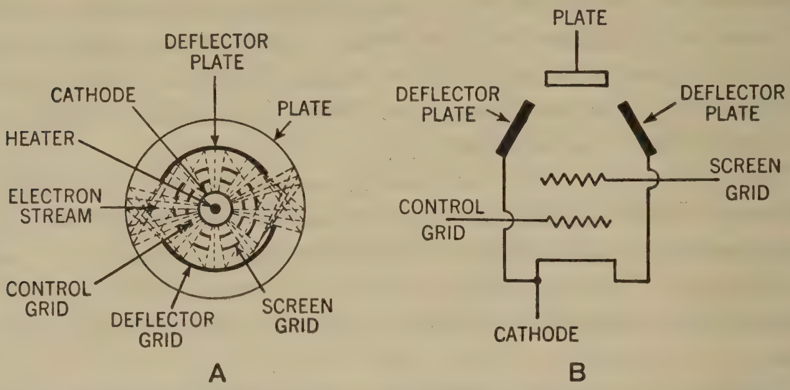


Figure 177. **A—Looking down on beam power tube, showing electron streams threading their ways through the grids.**
B—Arrangement of electrodes in the beam power tube.

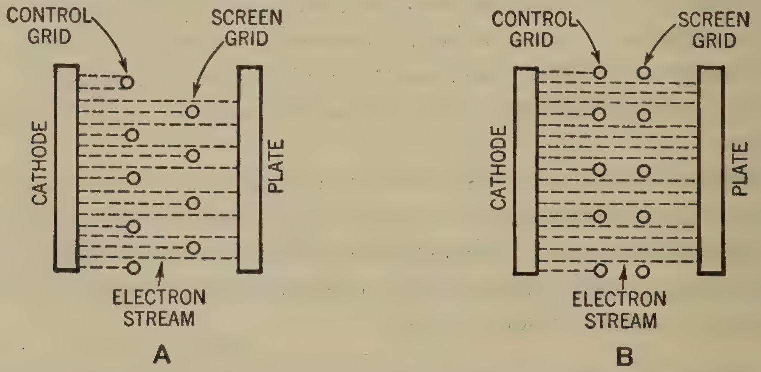


Figure 178. **A—Arrangement of control grid and screen grid in most tubes. Note that comparatively few electrons get through to the plate.**
B—Arrangement of control grid and screen grid in beam power tube. More electrons get through to the plate.

Another innovation of the beam power tube is the special construction of the grids. In other types of tubes the control grid and screen grid appear as shown in Figure 178-A.

Note that a considerable portion of the electrons hit the screen grid and thus are lost to the plate. If a meter were connected in the screen-grid circuit it would show a considerable flow of electrons from the screen grid to the B+ terminal.

Figure 178-B shows the construction of the beam power tube. Note that the wires of the control grid shade the wires of the screen grid in such a way that very few of the electrons hit the screen grid. A meter connected in the screen-grid circuit of a beam power tube accordingly would show a very small flow of current.

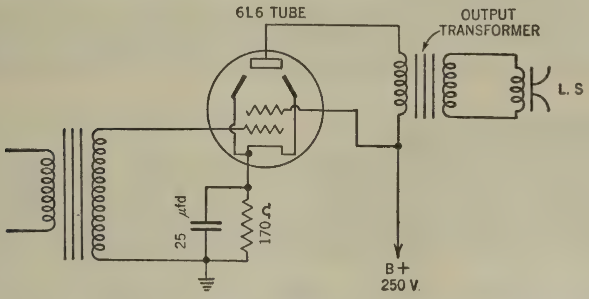


Figure 179. Circuit of beam power tube used as a power tube.

More electrons therefore strike the plate of a beam power tube and the efficiency of the tube is raised. Figure 179 shows how the 6L6 tube, a typical beam power tube, is connected in a circuit. Note that the positive charge on the plate is less than that upon the screen grid, since some of the electrical pressure is lost while forcing its way through the primary of the output transformer.

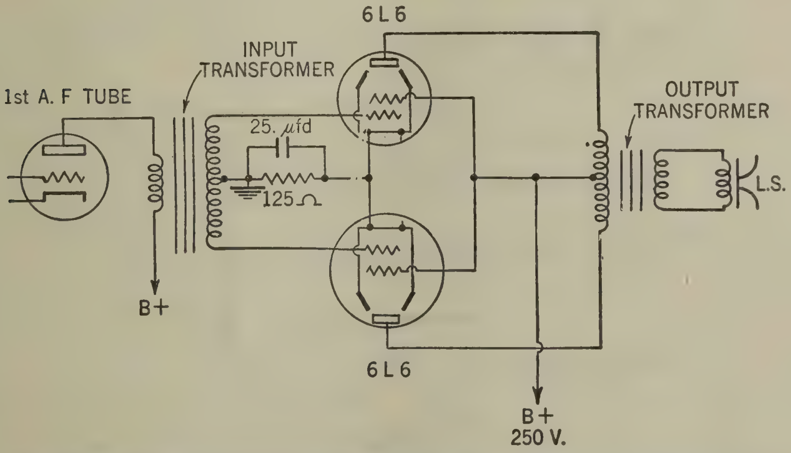


Figure 180. Circuit showing how two 6L6 tubes are hooked up in push-pull.

Some idea of the efficiency of such a beam power tube as the 6L6 can be gained by comparing it with a triode such as the type 45. With a charge of 50 volts applied to the grid, the type 45 tube delivers 1.6 watts of electrical power to the loudspeaker.

The 6L6 tube delivers 6.5 watts of electrical power and needs only 14 volts on the grid.

As in the case of other power tubes, the beam power tube can be connected in parallel and in push-pull to deliver greater power.

214. Multielectrode Tubes

Tubes containing more than five electrodes are generally called *multielectrode tubes.* Although they may appear quite complicated at first glance, their operation is quite simple if we keep in mind the basic principle of the vacuum tube, that is, that electrons are shot out by the heated cathode and find their way to the positively charged plate.

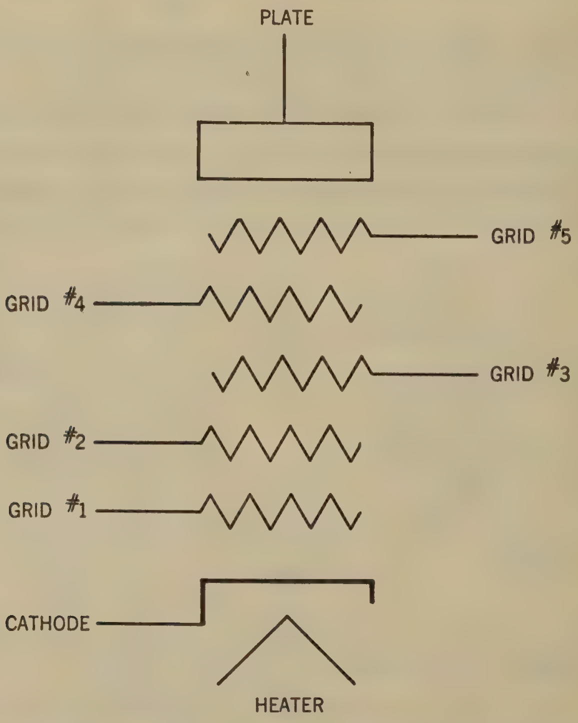


Figure 181. Diagram showing the arrangement of electrodes in the pentagrid converter tube.

In their travels the electrons pass between the wires or meshes of a number of grids. These grids either attract or repel the electrons, either speed them up or retard them. The effects that these grids exert upon the traveling electrons depend upon the charges placed upon the grids. A positively charged grid will attract the electrons, a negatively charged grid will repel them. A varying charge upon the grid will produce a varying effect on the electrons. And that is all there is to it.

215. The Pentagrid Converter

Let us take a look at the type 6A8 tube. This tube has a cathode (and separate heater), a plate, and five grids as shown in Figure 181. The grids are numbered from 1 to 5 counting from the cathode toward the plate.

This tube is often used as both the mixer (first detector) tube and oscillator tube in a superheterodyne receiver (see Chapter 26).

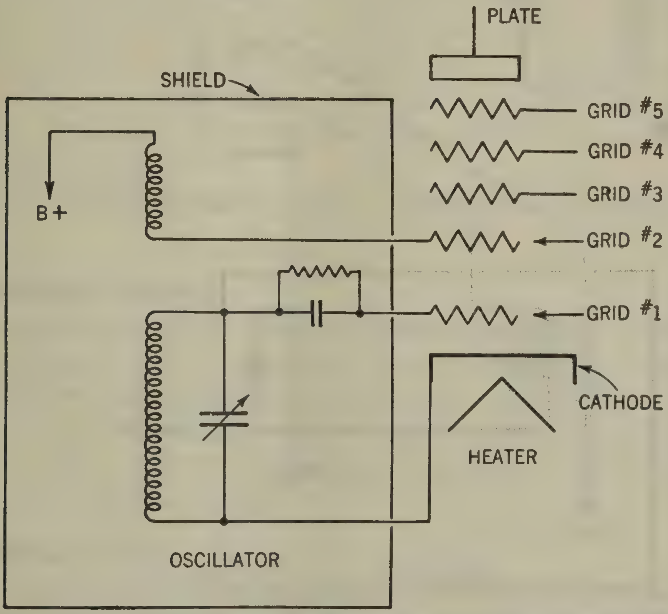


Figure 182. Circuit showing how cathode, grid #1 and grid #2 of the pentagrid converter are used as a triode for the oscillator section of the superheterodyne receiver.

When used for this purpose it is called a *pentagrid* (*five grids*) *converter*. Here is how it works.

First consider the cathode and grids 1 and 2 of the tube. If we place a positive charge upon grid 2 and call it the anode or plate, and call grid 1 the control grid, you can readily recognize our old friend the triode. Now let us hook up this triode as an oscillator as described in Chapter 26.

The electrons are shot out from the cathode in a steady stream. In the oscillator circuit, however, the electrons are dashing back and forth at a tremendous rate, at a frequency of 1,175 kc. per second if we use the example in Chapter 26. Grid 1 will therefore have a charge on it that will vary 1,175,000 times per second. This variation will cause the steady electron stream from the cathode to vary or fluctuate in step. This fluctuating stream will be attracted to the positively charged grid 2, but since this is a

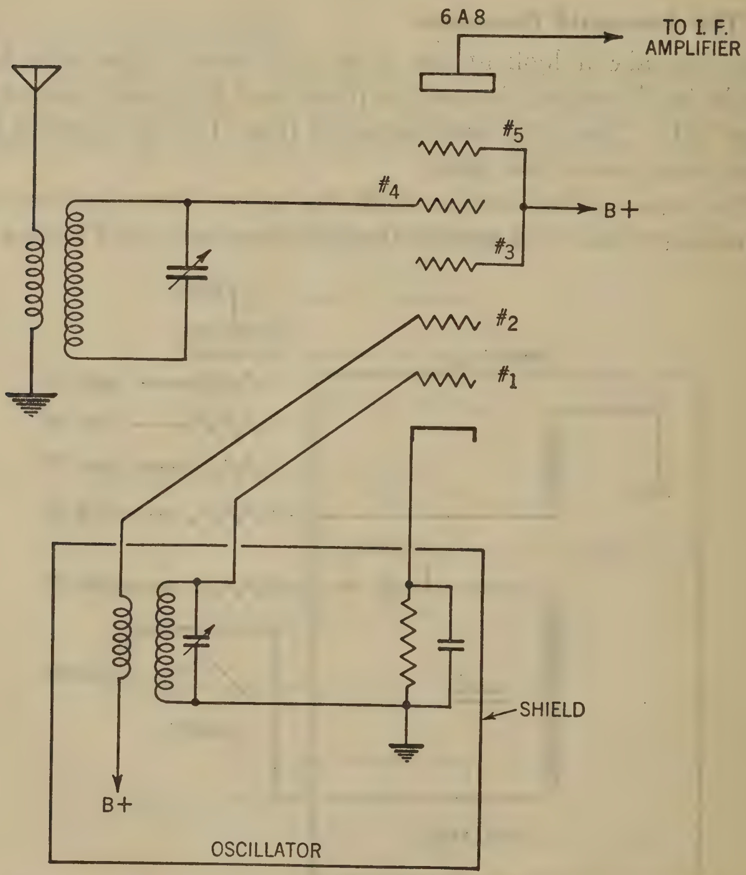


Figure 183. Complete circuit showing the pentagrid converter as the first detector, mixer, and oscillator tube in the superheterodyne receiver.

grid and not a solid plate, the electrons will shoot through the meshes on their way toward the real plate of the tube.

Thus we may really consider the combination of cathode, grid 1, and grid 2 as a composite cathode, sending out a stream of electrons that are not steady, but fluctuate at the rate indicated by the oscillator, that is, 1,175 kc. per second.

We may now consider the entire tube as a screen-grid tube. The cathode and grids 1 and 2 are the composite cathode, grid 4 is the control grid, and grids 3 and 5 are tied together and connected to the B+ terminal to furnish the screen grid and to shield grid 4 from the oscillator circuit.

The incoming signal, the modulated radio-frequency voltage (1,000 kc. in our example), is fed into the control grid 4. Thus a charge that fluctuates 1,000,000 times per second is placed on this grid 4.

Streaming through this grid is a flow of electrons that already are fluctuating at the rate of 1,175 kc. per second. Beats result, and out of grid 4 comes a stream of electrons that fluctuate at the rate of 1,175 kc. minus 1,000 kc. per second, or 175 kc. per second—the exact frequency to which the intermediate-frequency transformers are tuned.

Figure 183 shows the complete circuit for the pentagrid converter.

216. Electronic Coupling

You will recall that when we discussed coupling the oscillator to the mixing circuit in Chapter 26 we said that in addition to the inductive and capacity methods there was a third method whereby the two circuits were coupled through the electrodes within the tube. This third method is sometimes called *electronic coupling* for obvious reasons.

217. Multiunit Tubes

It is quite possible to place two or more complete tubes in one envelope. Such tubes are called *multiunit tubes.* All the tubes in the envelope may even share the same cathode, but they differ from the multielectrode tube in one important way. Whereas in the multielectrode tube there is one stream of electrons that is acted on by all the electrodes, in the multiunit tube the stream of electrons flowing from the cathode divides into two or more parts and each part flows through its own unit of electrodes.

These tubes are constructed so that the electron stream of one unit is not affected by the electrodes making up any other unit, but proceeds to flow from the cathode through its various grids (if any) to its own plate.

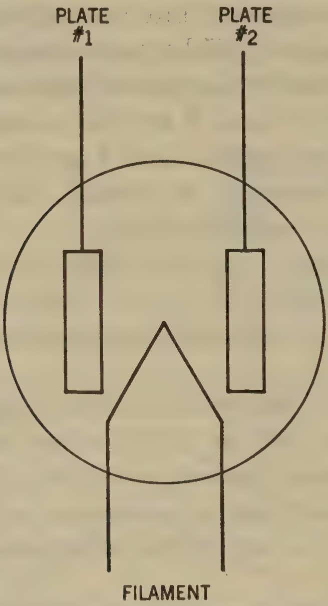


Figure 184. Diagram of a duo-diode tube. The type 80 is an example.

One of the simplest of these multiunit tubes is the type 80 shown in Figure 184, which is used as a full-wave rectifier. Here the electrons shot out by the filament follow two paths, one to plate 1, the other to plate 2.

Figure 185 shows the diagram for the 1H5-G tube, which has a diode and triode in one envelope.

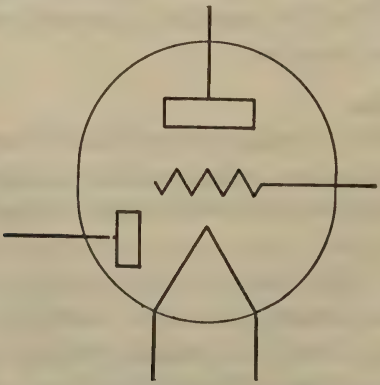


Figure 185. The 1H5-G tube. One diode—one triode.

Figure 186 shows a diode and a pentode in the same envelope. This tube is of type 1S5.

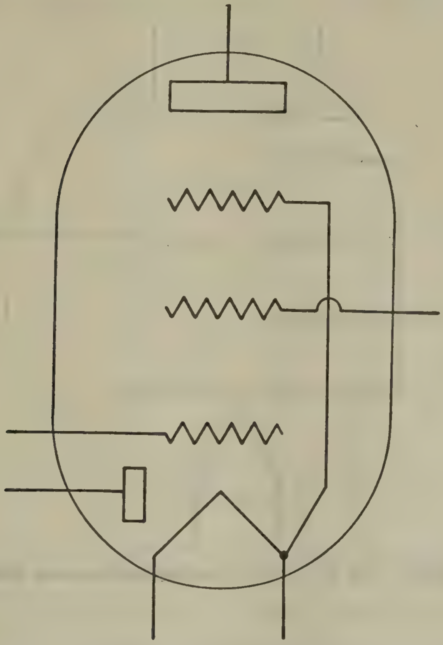


Figure 186. The 1S5 tube. One diode—one pentode.

In Figure 187 we see the 6C8-G tube, which has two triodes in one envelope.

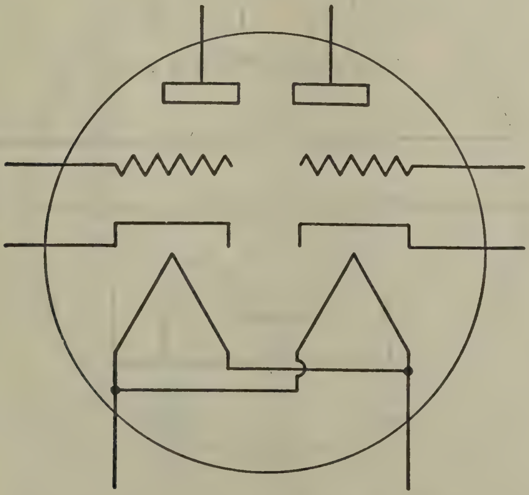


Figure 187. The 6C8-G tube (two triodes).

In Figure 188 we see the type 6F7 tube, which has one triode and one pentode in the same envelope.

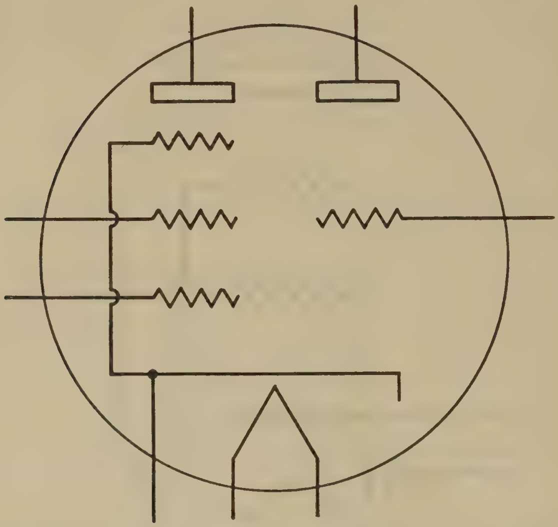


Figure 188. The 6F7 tube (one pentode—one triode).

The type 1E7-G tube (Figure 189) has two pentodes in the same envelope.

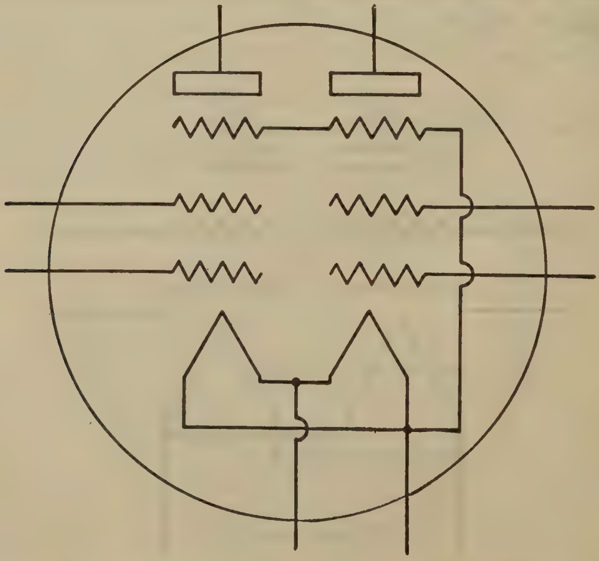


Figure 189. The 1E7-G tube (two pentodes).

The electron stream may be divided into three parts and thus make possible three distinct tubes in one envelope.

The 2A6 tube is an example, having two diodes and a triode.

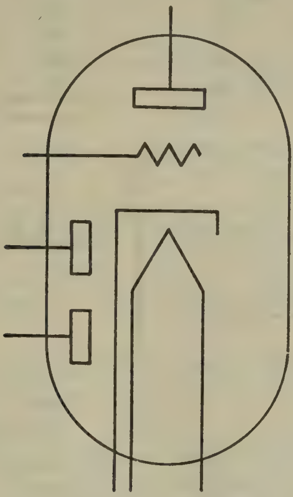


Figure 190. The 2A6 tube (two diodes—one triode).

Another such tube is the 2B7, which has two diodes and one pentode in the same envelope (Figure 191).

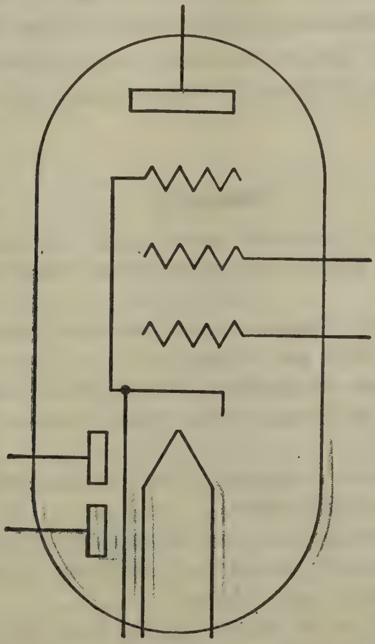


Figure 191. The 2B7 tube (two diodes—one pentode).

The 1D8-GT tube (Figure 192) contains a diode, a triode, and a pentode in one envelope.

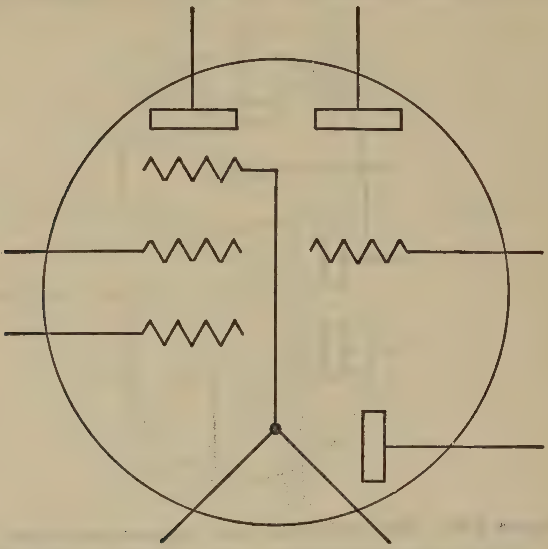


Figure 192. The 1D8-GT tube (one diode—one triode—one pentode).

Of course, many other combinations can be designed, and will. But regardless of how complex they seem to be, the basic principle is a simple one. A heated cathode emits a stream of electrons which threads its way through intervening grids to a positively charged plate.

SUMMARY

1. The fundamental principle operating in all vacuum tubes is that electrons emitted by a filament or cathode find their way to a positively charged plate.
2. Tubes with only a filament and plate are diodes; tubes with filament, grid, and plate only are triodes.
3. Tubes having more than five elements, called multielectrode tubes, are made by adding additional grids with various charges and mesh design.
4. When two or more complete tubes are enclosed in one envelope, the tube is called a multiunit tube.
5. In multielectrode tubes only one stream of electrons passes, while in multiunit tubes there may be several different streams of electrons, each one on its way to its own plate.
6. Students of radio must learn the numbers and uses of important commercial tubes.

GLOSSARY

Amplification Factor (*mu*): The ratio between a change in the grid voltage and a corresponding change in plate voltage needed to bring the plate current back to its original value.

Beam Power Tube: A pentode wherein the suppressor grid is often replaced by a slow-moving beam of electrons.

Control Grid: The grid of a tube upon which the signal voltage is impressed.

Cross Modulation: A condition in which a strong local signal comes in with sufficient strength to force the first radio-frequency tube to act as a detector, thus producing distortion.

Electronic Coupling: A method of coupling electrical energy from one circuit to another through the stream of electrons in a tube.

Grid Swing: The amount of grid voltage variation needed to operate the tube.

Multielectrode Tube: A tube with many electrodes, mainly grids, each of which acts on the single stream of electrons flowing from the cathode to the plate.

Multiunit Tube: A tube combining several independently acting tubes in one envelope. The electron stream divides into several parts, each part being acted upon by one set of electrodes.

Pentagrid Converter: A tube containing five grids in addition to the plate and cathode. This tube is used in the superheterodyne receiver to perform the functions of first detector, local oscillator and mixer tubes at one and the same time.

Pentode: A five-element tube containing a cathode, plate, control grid, screen grid, and suppressor grid.

Power Tube: A tube designed to handle more current than the ordinary amplifying tube. This tube is used in the last stage of the audio-frequency amplifier.

Power sensitivity: A measure of the extent to which small changes in grid voltage control large changes of power in the plate circuit of a tube.

Push-pull: A method of connecting two tubes to supply great power to a loudspeaker with little distortion.

Screen Grid: A grid of a tube placed between the control grid and the plate to reduce the space charge and plate-to-grid capacitance.

Secondary Emission: The cloud of electrons knocked out of the plate by the impact of the electron stream sent out by the cathode.

Space Charge: A cloud of electrons filling the space between the cathode and plate of a tube.

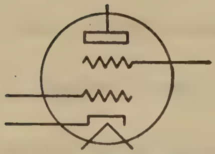
Supercontrol Radio-frequency Amplifier Tube: A variable-*mu* tube.

Suppressor Grid: A grid placed in a tube between the screen grid and the plate to reduce the effect of secondary emission.

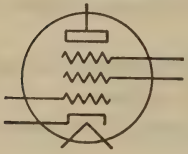
Tetrode: A four-element tube containing a cathode, plate, control grid, and screen grid.

Variable-*mu* Tube: A tube with a specially wound grid producing a change in the amplification factor with signals of different strength.

SYMBOLS



Tetrode.



Pentode.

QUESTIONS AND PROBLEMS

1. Thin-filament tubes are usually heated by what type of current?
2. Describe the structure of a diode.
3. For what may a diode be used?
4. What is meant by the amplification factor of a tube?
5. The introduction of what tube element made amplification by a tube possible?
6. Describe the structure of a triode.
7. What determines the *mu* of a tube?
8. Why do triodes have relatively low amplification factors?
9. How does a power tube differ from other tubes?
10. What is generally true of the *mu* of power triodes?
11. Why must we have an audio-frequency voltage amplifier between detector and power tube of a receiver?
12. Draw the diagram of two power tubes in parallel.
13. Explain the operation of a push-pull power stage.
14. Compare the qualities and characteristics of a power stage consisting of two tubes in parallel and of a push-pull power stage.
15. Describe the structure of a tetrode.
16. What effect does the introduction of a screen grid have on the tube's functioning?
17. Compare the values of grid-plate capacitance in a triode and a tetrode.
18. What gives the tetrode a higher *mu* than a triode?
19. How does the use of a tetrode eliminate the need for neutralization in the radio-frequency amplifier stage?
20. What is cross modulation? How is it eliminated?
21. What is secondary emission of a tube? How is it overcome?
22. Draw a schematic diagram of a pentode.
23. What are the requirements of a good power amplifier tube?
24. Explain the operation of a beam power tube.

25. What are multielectrode tubes?

26. Explain the operation of a pentagrid converter as a first detector and oscillator.

27. How does a multiunit tube differ from a multielectrode tube?

28. What is the basic principle of all tubes regardless of complexity?

CHAPTER 28

Radio Direction Finders

Problem 1: *In what position relative to a radio wave does an aerial get maximum reception?*

Problem 2: *How does a loop aerial serve to determine the direction of a transmitting station?*

Problem 3: *How do airplane pilots guide their flight by radio signals?*

For most of us, the radio receiver means entertainment and enjoyment at home. Radio networks crisscross our country and there is hardly a locality outside the range of at least one powerful transmitting station.

218. Importance of Direction Finders

Under such conditions, the directional quality of the aerial, that is, the ability to receive better from one direction than from another, means little. The aerial is usually strung in the most convenient location to give it a position fairly high and reasonably clear of obstructions.

But ships at sea, airplanes in the sky, and armies in the field find it highly important to obtain accurate information about their location. It is here that the directional quality of the aerial serves a useful purpose.

219. Direction Finders Depend on Difference in Electrical Pressure

Whenever a radio wave passes across an aerial, it sets up an electrical pressure that causes electrons to flow in the aerial-ground system.

Now an electrical pressure by itself will not cause electrons to flow. There must be a *difference* between electrical pressures at two points. The electrons flow from the point of *high pressure* to the point of *low pressure*. If the pressure were *equal* throughout, there would be no flow of electrons, no matter how high this pressure might be.

During one half cycle, therefore, the radio wave places a negative charge (high electron pressure) on the top or antenna of the aerial-ground system and a positive charge (low pressure) on the bottom or ground of the system. The electrons then flow *down* the aerial-ground system from the high-pressure point to the low-pressure point (Figure 193-A).

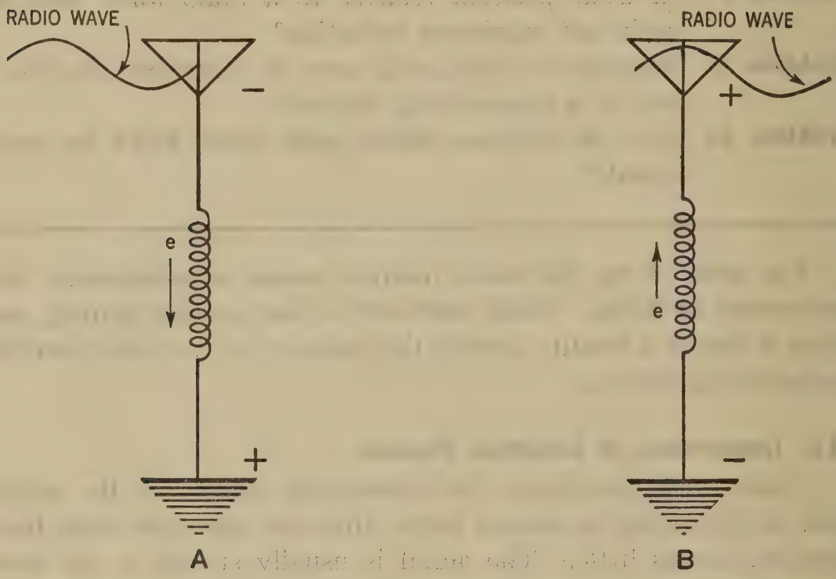


Figure 193. **A—Charges placed on the aerial-ground system and flow of electrons as one half cycle of the radio wave passes the aerial.**
B—Charges and flow of electrons as the next half cycle of the radio wave passes the aerial.

On the next half cycle, the charges or pressures are reversed and the electrons stream *up* the aerial-ground system. (Figure 193-B.)

220. Reception from a Single-wire Aerial

We are now ready to learn why our simple, straight-wire aerial described in Chapter 5 can receive better from one direction than from another. Consider Figure 194-A.

All parts of the aerial are at the same distance away from the transmitting station. The radio wave therefore strikes all parts simultaneously. Thus the electrical pressure in all parts of the aerial is the same and there is little or no flow of electrons.

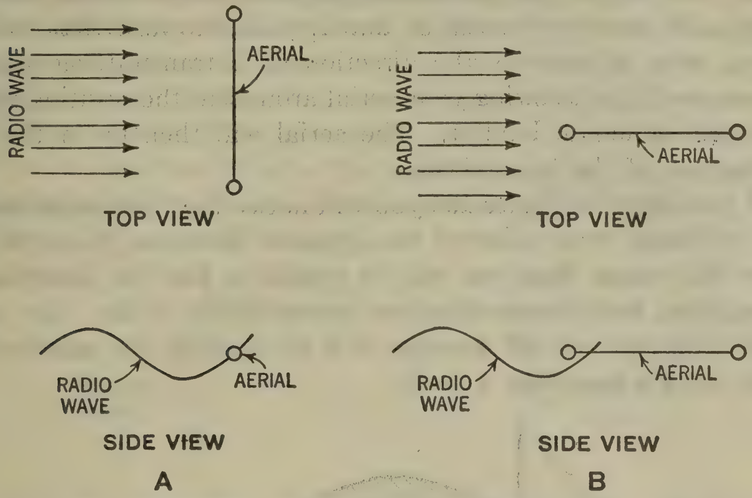


Figure 194. A—Diagram showing aerial broadside to the radio wave. Note that all parts of the aerial are struck simultaneously.
B—Diagram showing aerial pointing toward the oncoming radio wave. Note that one end of the aerial is struck first.

In Figure 194-B, however, the front of the aerial is nearer the transmitter than is the rear. The radio wave therefore strikes this front part first and at that instant there is a difference of electrical pressure between the front and rear of the aerial and a flow of electrons results.

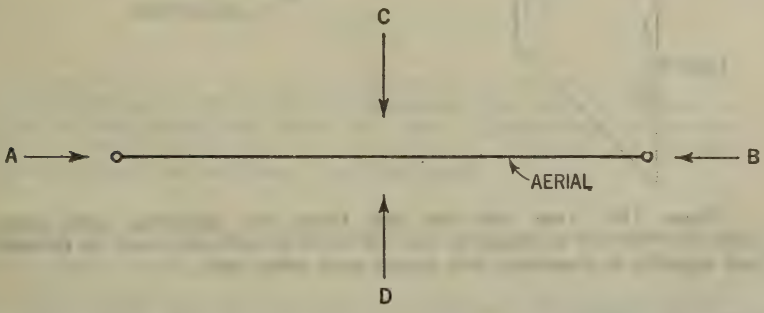


Figure 195. Diagram showing why signals from directions A and B will be heard louder than signals from directions C and D. The radio waves coming from A and B set up a difference of electrical pressures in the aerial.

From the above, we can see that we will get louder reception if the aerial of the receiver points into the radio wave coming from the transmitter.

If you desire to get maximum reception from a certain station, you should erect your aerial so that it points toward that station. If you wish to discover the direction of a transmitting station, all you need do is to swing your aerial around to the position where the signal comes in loudest. The aerial will then be in the line of direction of the transmitter.

If you examine Figure 195 you will notice that maximum reception will come from either of the opposite directions A and B. It is for this reason that you will be unable to find the direction of the station, but merely the line along which it lies. In other words, you can not tell whether it is at A or B, but merely that it lies along a line from A to B.

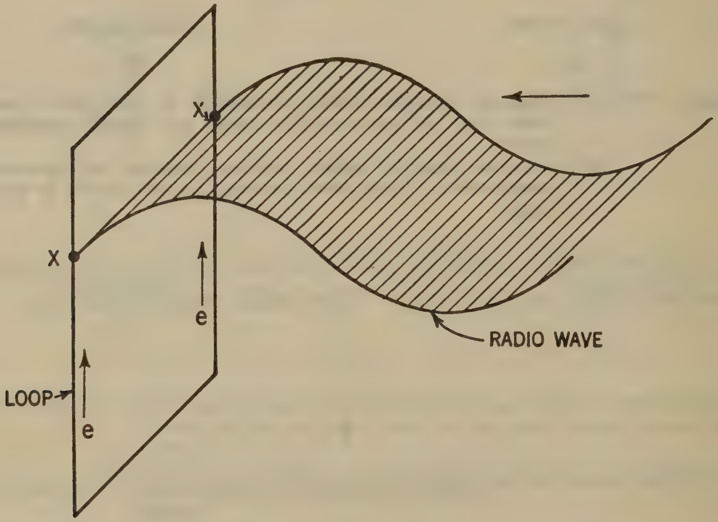


Figure 196. Loop with flat side facing the oncoming radio wave. Since the flows of electrons in the two vertical parts are equal in strength and opposite in direction, they cancel each other out.

221. The Small Loop Aerial

Of course, swinging a 100-foot aerial is not a convenient thing to do, especially aboard an airplane. A simpler method must be devised.

The extreme sensitivity of the superheterodyne receiver is utilized for this purpose. You will recall that a small loop antenna is sufficient to operate this set. Since it is easy to rotate this small loop, our problem is solved.

Imagine a loop of wire in space, so placed that the flat side of the loop faces the oncoming radio wave (Figure 196).

The horizontal arms of the loop act like our straight-line aerial in its least efficient position and little or no flow of electrons occurs in them because there is little or no difference in electrical pressure between points in them. In the vertical arms, however, there is a flow of electrons because the wave strikes different points on these arms at different times and thus creates a difference of pressure.

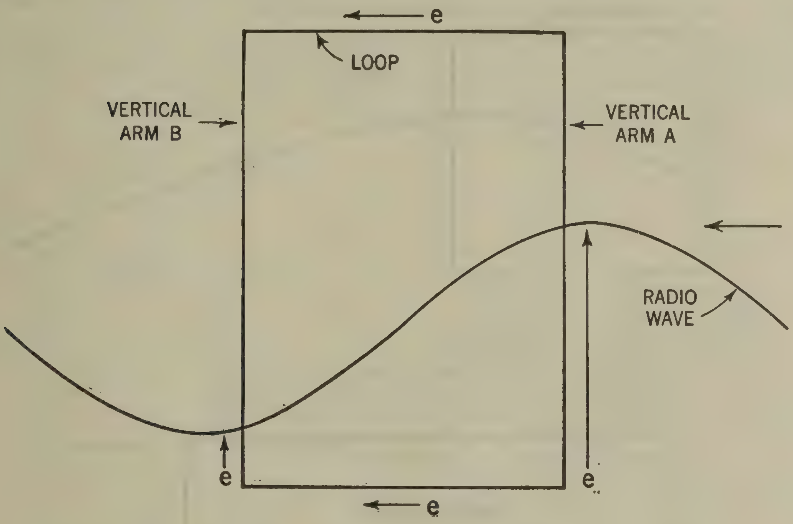


Figure 197. Loop with edge facing the oncoming radio wave. Since the horizontal arms are struck simultaneously, the electron streams set flowing in them cancel each other out. But a greater electrical pressure exists in vertical arm A than in vertical arm B. Electrons will therefore circulate through the loop from arm A to arm B.

But corresponding points on each vertical arm are struck simultaneously and therefore the electrons are set flowing in these arms in the same direction at the same time (*up* in Figure 196) and with equal pressure. Since the electron streams in each of the vertical arms are equal and flow toward each other, these streams cancel themselves out, hence we have no electron flow into the receiver, and therefore nothing can be heard.

Now rotate the loop 90 degrees, so that the edge of the loop faces the oncoming radio wave (Figure 197).

Since the radio wave passes corresponding points on the horizontal arms at the same time (the points nearest the transmitter), the electron streams set flowing in these arms are equal and opposite to each other. They therefore cancel out.

But vertical arm A is nearer to the transmitter than is vertical arm B. The electrical pressure in arm A is therefore greater than that in arm B, and although the electron streams are in opposite direction, the greater pressure in arm A overcomes that in arm B and electrons are set flowing through the loop in a counterclockwise direction. If we now connect a receiver to the loop, these electrons will stream into it and we will be able to hear the signal.

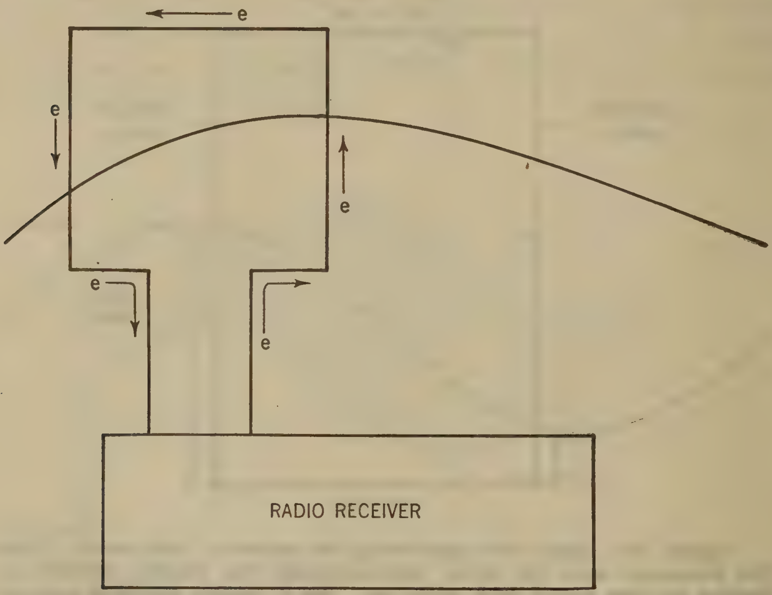


Figure 198. The flow of electrons in the loop is sent into the radio receiver and the signal is heard.

All we need do, therefore, is to rotate the loop antenna until the signal is heard at its *loudest* and the edges of the loop will be along the line of direction of the transmitting station.

222. Direction Is Best Determined from the Weakest Signal

In practice we reverse this procedure. We turn the loop until its flat side faces the oncoming radio wave. We then hear the signal at its *weakest;* there is little or no sound. The reason for doing this is that it is easier to distinguish between a weak signal and no signal than it is to distinguish between the loudest signal and that which is nearly as loud. Hence weak signals help us to determine more accurately than do strong signals when we have located the direction of the transmitter. The position of the loop that gives us the weakest or zero signal is called the *null position.*

The loop antenna is tuned to the frequency of the radio wave by means of a variable condenser, just like the tuning circuit of the receiver. Since it is essential that an exact balance be established in the arms of the loop before this balance is upset by the incoming signal, a balancing variable condenser is connected across the loop. The action of this balancing condenser is similar to that of the trimmer condensers used in aligning the receiving set. After the loop is tuned and balanced it is connected across the input of the first radio-frequency amplifier tube and the signal is amplified just as in the case of an ordinary receiver (see Figure 199).

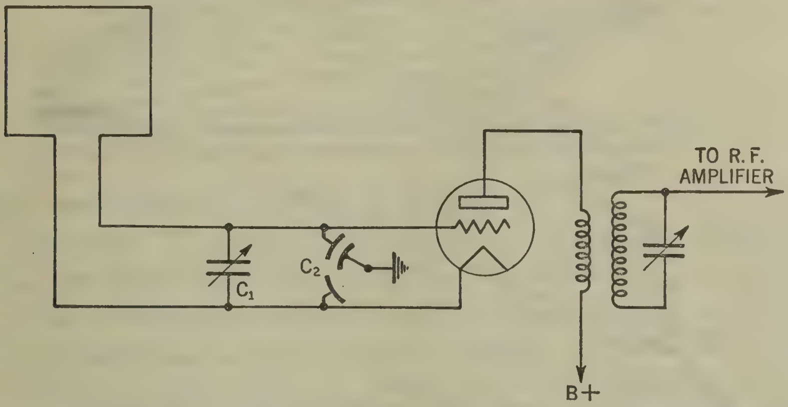


Figure 199. Diagram showing how the loop is coupled to the radio receiver. Variable condenser C_1 tunes the loop to the incoming signal. C_2 is a balancing condenser.

223. What Is "Sense of Direction"?

But so far we have covered only half the story. By rotating the loop antenna we can determine the line of direction along which the transmitter is located. We can tell that it is located on a line running, for example, from east to west. But we can not tell whether it is east or west of us. We say that we have the *line of direction,* but not the *sense of direction.*

Of course, this distinction does not matter when a receiver on the shore is locating a transmitter on a ship at sea. But two ships at sea or two airplanes in the sky cannot tell on which side of them the transmitter is located. Further, they have no indication as to how far from them the transmitter may be.

224. Locating the Position of a Ship by Radio

These difficulties may be overcome in a number of ways. Assume that a ship at sea wishes to find its exact location. It sends out a radio signal which is received simultaneously by two receiving stations located on the shore. Each of these stations determines the line of direction from it to the ship. This line is marked on a map. By telephone, one of the stations informs the other of its findings. It then becomes a simple operation for the operator at the second station to draw both lines of direction on a map. Where the two lines cross, there is the location of the ship. This location is then radioed to the waiting ship.

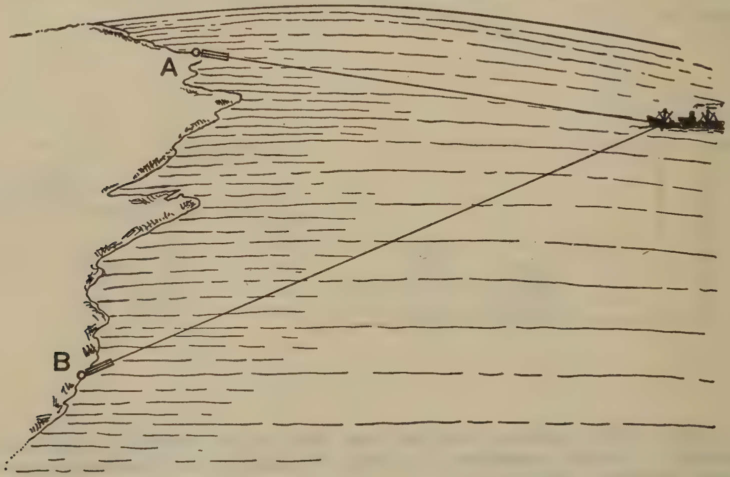


Figure 200. Diagram showing how two receiving stations on land combine to find the location of a ship at sea.

Another method is the reverse of this procedure. Along the shore there are located, at certain designated points, transmitting stations which automatically and continuously send out radio waves. To identify these stations, each one sends out a different signal. Thus one may continuously send out three dots. Another may send out two dots.

A ship at sea, wishing to know its location, finds the line of direction between it and one of the automatic sending stations. This is called *taking a bearing*. Knowing the location of the transmitter, the navigator plots this line of direction on a map. He then takes a bearing on another such station and plots its line of direction on the same map. Where these two lines cross is the location of the ship.

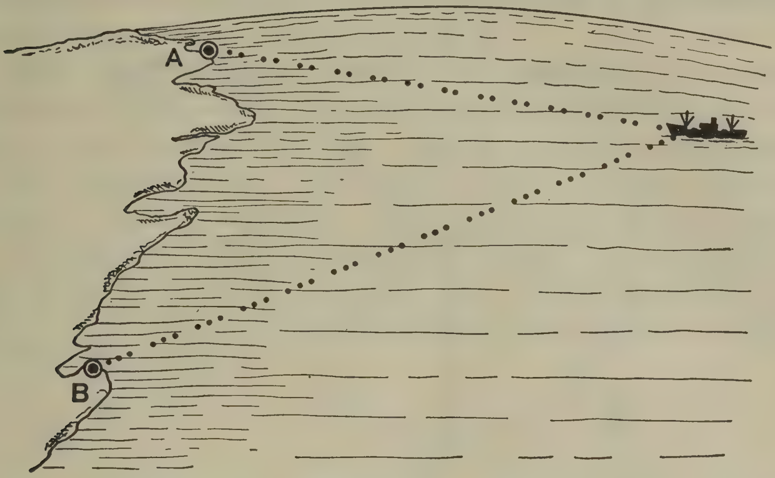


Figure 201. Diagram showing how a ship at sea can obtain its location from two automatic transmitting stations located on land.

225. The Problem of a Pilot in a Bomber

Note that the above methods require two stations whose positions are fixed and whose locations are known. But a Navy bomber, seeking its way back to its aircraft carrier, can get its bearing from only one station, the carrier. Further, this station is not fixed; it moves as the carrier twists and turns to avoid the enemy. A new method of direction-finding had to be developed to meet these conditions. This new method had to give not only the line of direction but the sense of direction as well, so that the airplane could fly directly to the mother ship. And direction had to be found quickly and without any need for plotting lines upon a map. Let us see how this new method was developed.

226. Method of Finding Direction in a Plane by Radio

Assume that you have erected a single vertical wire as an antenna, with the bottom end connected to a radio receiver. Further assume that this vertical antenna is surrounded by a circle of transmitters, each of equal power and located an equal distance from the antenna. Signals then will be received from all directions with equal strength. We say that a vertical antenna is *nondirectional.*

We can show this nondirectional quality of a vertical antenna graphically by drawing a circle about the antenna as a center, as in Figure 202.

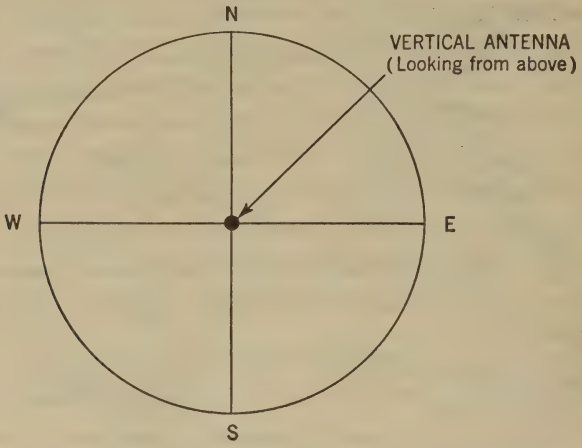


Figure 202. The pattern of the directional characteristics of a vertical antenna.

The lines running from the center to the circumference of the circle indicate the relative ability to receive signals from these directions to which they point. The nondirectional quality of the vertical antennas can be seen from the fact that all these lines are of equal length.

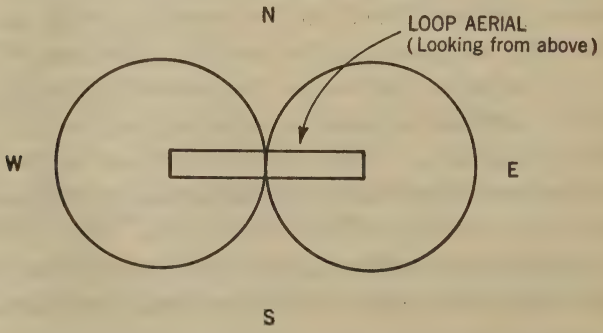


Figure 203. The pattern of the directional characteristics of a loop aerial.

We call the circle the *pattern* of the directional characteristics of the vertical antenna.

Now let us put a loop aerial in place of the vertical antenna.

Stations perpendicular to the face of the loop (N and S in Figure 203), will not be heard, while stations facing the edges of the loop (E and W in our diagram) will come in strongest. The pattern of the directional characteristics of the loop antenna becomes a figure 8 as shown in Figure 203.

Here is another way of looking at it. Since we have seen that the radio wave has little or no effect on the horizontal arms of the loop, we may consider the loop aerial to be two vertical antennas a little distance apart. The pattern about each such vertical antenna is a circle and the two circles combine to give us a figure 8.

From the pattern of the loop aerial we can now see the advantage of taking a null bearing upon the transmitting station. Assume that the edge of the loop has been pointed at the transmitting station (Figure 204-A).

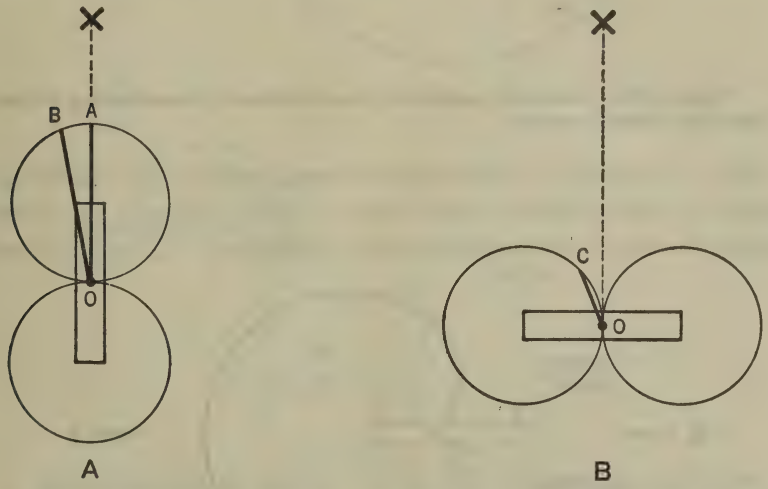


Figure 204. Diagram showing why it is better to take a null bearing rather than to turn the loop to maximum signal strength.

The line OA in the direction of X represents the strength of the signal received. If an error of, say, five degrees is made, the line OB would indicate the strength of signal. You can see that OA and OB differ little in length and why it is hard to discern the error.

But assume you have turned the face of the loop towards X. If this face is exactly perpendicular to the radio wave coming from X, no signal will be received. But an error of 5 degrees will give us line OC, which will bring the signal in loud enough for us to discern the deviation (Figure 204-B).

So we have our loop aerial with its figure 8 pattern. Now, through the center of the loop erect a vertical antenna. The combined pattern of the two aerials will then appear as shown in Figure 205.

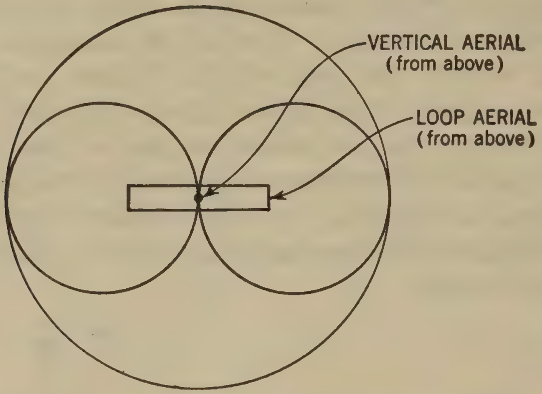


Figure 205. Combined pattern of the directional characteristics of the loop and vertical aerials.

Now, by means of a transformer arrangement, the electrons set flowing in the vertical aerial start a second stream of electrons flowing in one of the vertical arms of the loop. This flow unbalances the pattern of the loop and the new pattern is shown in Figure 206.

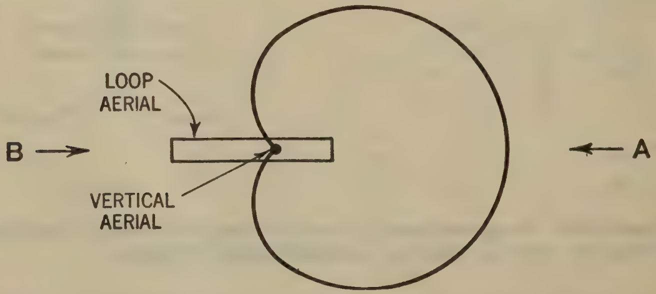


Figure 206. Combined pattern of the directional characteristics of the loop and vertical aerials when the current flowing in the vertical aerial is inductively coupled to one of the vertical arms of the loop aerial. The pattern is cardioid or heart-shaped.

You will notice that our new aerial can receive better from one direction, A, than from the other. We can now obtain the sense of direction, that is, we can tell from which side the signal is coming.

The vertical antenna is called the *sense aerial.* To operate our direction finder, we open the switch and take a null bearing with the loop to determine the line of direction. Then we close the switch, connecting the sense aerial into the circuit. We now turn the loop until the signal comes in at its loudest. A pointer, connected to the loop, indicates the direction from which the signal is coming (Figure 207).

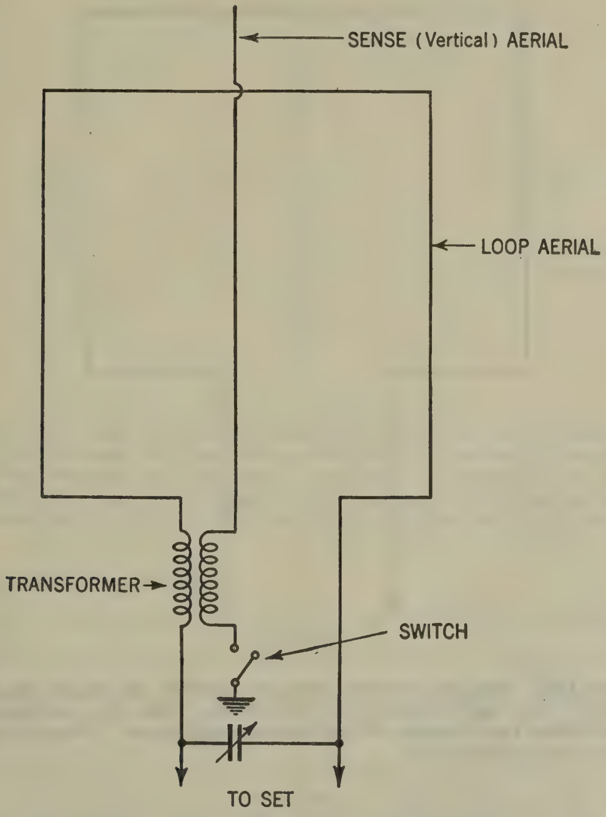


Figure 207. Circuit showing how the sense (vertical) aerial is coupled to the loop aerial.

227. A Bombing Plane Returning to a Carrier

If the airplane navigator wishes to reach his carrier, he first finds the direction of the boat. He then fixes his loop aerial so that it is at right angles to the axis of the airplane and then the plane is turned until the loop is in the null position with respect to the radio wave from the carrier. As long as the plane is flying along the radio wave the loop remains in the null position and he will hear no signal. The electron stream in one vertical arm of the loop balances out the stream of the other.

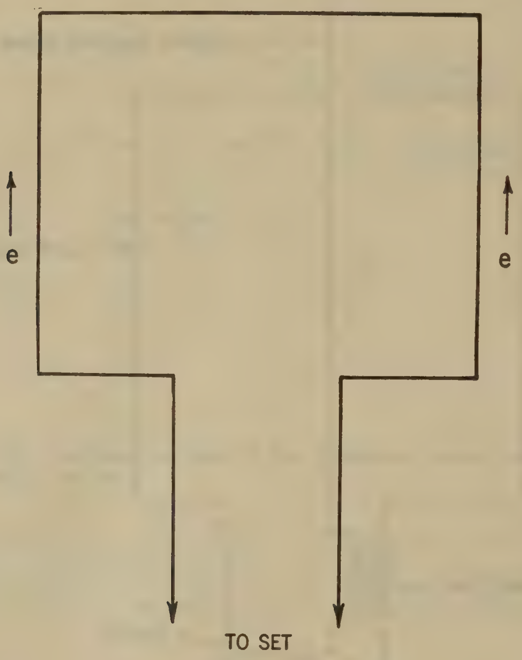


Figure 208. Diagram showing how the electron streams in the vertical arms of the loop aerial cancel out each other when the navigator turns the face of the loop toward the oncoming radio wave. There is no flow of current into the radio set.

Should the plane deviate from its course toward one direction, the balance is upset and the electrons stream through the loop in, say, a clockwise direction. Should he deviate in the other direction, the balance is upset again and the electrons stream in a counterclockwise direction.

228. The Radio Compass

If an electric meter is connected to the airplane's loop aerial, it shows no current flowing through it when the plane is on the course. The needle then rests in the center of the meter. When the flight deviates to the right, the electrons flow through the meter in one direction and the needle swings to the right. When it deviates to the left, the needle swings to the left.

This hookup is called a *radio compass* or *homing device.*

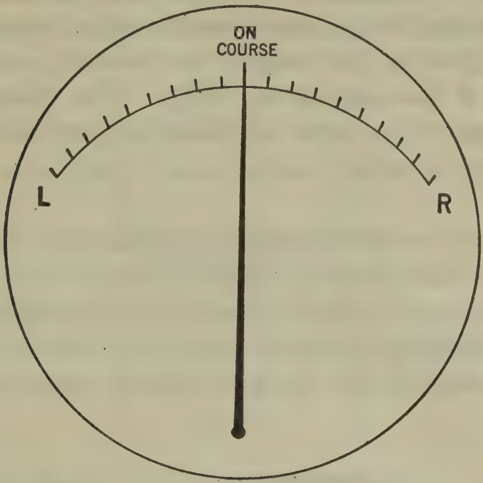


Figure 209. Dial of the radio compass. As long as the face of the loop aerial is towards the oncoming radio wave no current flows and the needle is at the zero or "on course" position in the middle of the dial. As the airplane turns to the right or left, current is set flowing and the needle swings to the right or left, indicating the deviation from the course.

229. Corrections for Errors

There are a number of sources of error in the direction finder. One of these is unbalance in the loop circuit. This error is eliminated through the use of the balancing condenser described above and by calibrating the loop to compensate for deviations.

Another source of error is the presence of stray electric fields set up by atmospheric disturbances. This source may be eliminated by shielding the loop with a nonmagnetic metal similar to the shielding of the radio-frequency transformers.

Large metallic objects, wires, and other conductors near the loop may cause trouble. The obvious remedy is to place the loop where it cannot be affected by these materials.

Ignition wires in an airplane set up magnetic fields which might interfere with the operation of the direction finder. The remedy is to enclose these wires in iron pipes, which absorb the magnetic field.

Still another source of trouble is called *night error.* In all our discussions we considered radio waves as though they traveled parallel to the surface of the earth. This view is not strictly true.

230. The Sky Wave and the Heaviside Layer

In addition to sending out a radio wave that travels parallel to the earth, the radio transmitter sends out a wave that goes up into the sky. It might be thought that this *sky wave* travels out into space; but it does not do so. Why? The theory is that high up above the earth is a layer of electrified particles of air which acts like a mirror to reflect the sky wave back to the earth (Chap. 35, Vol. II).

This layer of electrified particles is called the *Heaviside-Kennelly layer* and shifts from a height of about sixty miles in the daytime to about two hundred miles above the surface of the earth at night. It is believed that the particles of air are electrified by the ultraviolet rays of the sun and by the cosmic rays from the stars.

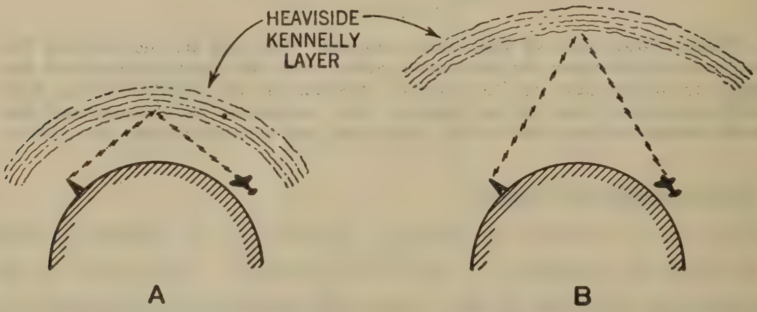


Figure 210. A—During the daytime the Heaviside-Kennelly layer is comparatively close to the surface of the earth. The reflected radio wave is traveling nearly parallel to the surface of the earth when it strikes the loop aerial of the airplane.
B—At night the layer lifts. Now the radio wave is almost perpendicular to the surface of the earth as it strikes the loop aerial of the airplane.

Because of the comparatively low altitude of this layer in the daytime the radio wave is reflected back to the earth at such an angle that it is very nearly parallel to the earth when it strikes our loop aerial and the error is therefore quite small. (Figure 210-A.)

But at night the Heaviside-Kennelly layer rises. The reflecting radio wave comes back to earth almost vertically. (Figure 210-B.) This change in direction upsets the balance in the horizontal arms of the loop because the radio wave now hits the top arm before it strikes the lower, thus setting up a difference in electrical pressure which causes electrons to flow around the loop.

This error is overcome by use of the *Adcock loop aerial.* This is a small aerial in the form of a letter H as shown in Figure 211.

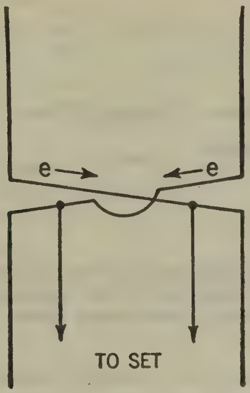


Figure 211. The Adcock loop aerial.

Since the two horizontal arms are very close to each other, the vertically approaching radio wave strikes them both almost simultaneously. Thus the electrical pressures in both these arms are very nearly equal and the electron streams are balanced out. When the vertical radio wave is eliminated the loop direction finder responds to the horizontal wave and functions as usual.

231. The A–N Radio Beacon

Airplanes flying over the networks of our commercial airlines make use of the radio beacon to keep them true to their course. Here is how it works.

At regular intervals along the course, usually about 125 miles apart, radio beacons are located. Each of these beacons is a radio station that sends out a narrow radio beam of signals. This radio beam really consists of two beams a degree or two apart. To set up this pair of radio beams two transmitting aerials are employed. First one aerial sends out a radio wave that consists of a dot and a dash (the letter A in the International Code) and then the other aerial sends out a dash and a dot (the letter N). These aerials are set up to send out their signals automatically and alternatingly.

Thus the pilot of an airplane flying in the A zone (Figure 212), would continually receive the letter A in his receiver and the letter N if he were in the N zone. But in the space between the two zones he would receive the A and the N equally well.

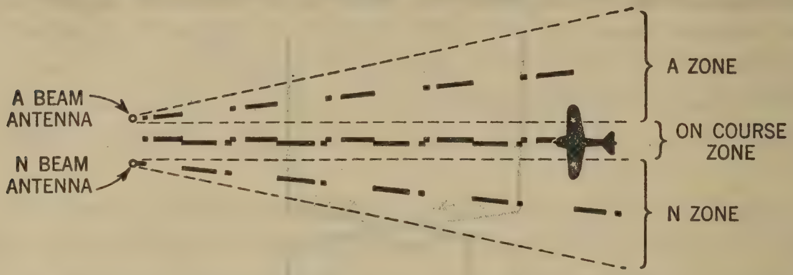


Figure 212. Diagram showing how the A beam and N beam overlap at the center to provide a zone where the airplane navigator hears neither A (. —) nor N (— .), but a continuous buzz.

Examination of Figure 212 shows that the pauses between the dots and dashes of the A signals are filled by the dots and dashes of the N signals. Thus, in the overlapping zone the airplane pilot will receive not dots and dashes, but a continuous buzz. This will show him that he is "on the beam," that is, on the course between the two zones.

Should he deviate from his course, he will enter either the A or N zone. He will then hear either the letter A or N. All he need do then is to turn about till he hears the continuous buzz again and he will be on the course once more.

To prevent interference, each radio beacon has its own frequency, lying between 200 kc. and 400 kc. Thus, when the pilot passes one such beacon, all he need do is tune his receiver to the frequency of the next beacon and continue on his course.

SUMMARY

1. A single-wire aerial receives incoming radio waves best when it is in line with the direction of the station.
2. The aerial determines the **line of direction** because of difference in electrical pressure at the ends of the aerial when pointed toward a broadcasting station.
3. The loop aerial, in conjunction with the superheterodyne receiver may be used to determine direction better than a single long aerial.
4. In a loop aerial set with the flat side facing the line of the radio wave, reception is weakest. When the face is at right angles to the direction of the radio wave, reception is best.

5. The **null position** of a loop aerial is the position when the flat side faces the direction of the radio beam.

6. **Sense of direction** means, in addition to the sense of line of direction, knowledge of the actual point of the compass from which the radio wave comes.

7. Airplane pilots use a radio compass to find their location or the location of their carrier.

8. In cross-country flying **radio beacons** are used to guide pilots from one station to another.

GLOSSARY

Directional: As applied to an aerial, the ability to receive signals better from some directions than from others.

Line of Direction: The line showing the directions from which signals are received at their best.

Night Error: Error in direction determination due to movements of the Heaviside-Kennelly layer, especially at night.

Nondirectional: As applied to an aerial, the ability to receive signals equally well from all directions.

Null Position: The position of a loop aerial for minimum signal pickup.

Pattern: As pertaining to an aerial, the geometric figure used to show the directional qualities of an aerial. Important patterns include the circle, the figure 8, the figure 8 and circle, and the cardioid or heart-shape.

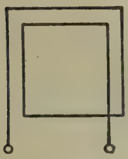
Radio Compass or Homing Device: A hookup and meter that indicates automatically and instantly when a plane or ship is off the line of direction.

Sense Aerial: A small vertical aerial used in conjunction with a loop aerial to give the operator a sense of direction.

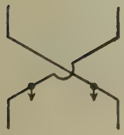
Sense of Direction: The direction, along the line of direction, from which a signal comes to the aerial of the receiver.

Sky Wave: The portion of the radio wave which is directed up to the sky. It is this sky wave that is reflected back by the Heaviside-Kennelly layer and causes the night error.

SYMBOLS



Loop aerial.



Adcock aerial.

QUESTIONS AND PROBLEMS

1. When will electrons flow in a circuit?

2. With the simple horizontal aerial, when do we get louder reception from any particular station?

3. Explain the radio-wave pickup of a loop in various positions.

4. Why do we tune with a loop for the weakest signal?

5. Of what circuit is the loop a part?

6. When tuned to a station and adjusted to the null point, what does the loop tell us about the station position?

7. How does a ship obtain its position from shore stations?

8. Why cannot an airplane locate an aircraft carrier at sea in the same manner as ships taking bearings from land stations?

9. Differentiate between "line of direction" and "sense of direction."

10. What is the reception characteristic of a vertical antenna?

11. Draw the pattern of the directional characteristics of a vertical antenna.

12. Draw the pattern of the directional characteristics of a loop antenna.

13. Draw the pattern of the directional characteristics of a combination of loop and vertical antenna.

14. How do we take a bearing with a combination loop and vertical antenna?

15. What is a radio compass or homing device?

16. List several sources of error in direction finding and their remedies.

17. What is night error and what is one means of overcoming it?

18. Explain the operation of the A-N radio beacon.

Demonstrations

Chapter 2

Demonstration 1: *To show how energy is handed on by wave motion.* Set up a row of dominoes, so spaced that when one falls it upsets its neighbor. Tip the first and note how energy is handed down the line without any domino moving more than a small distance. (See Figure 4).

Chapter 3

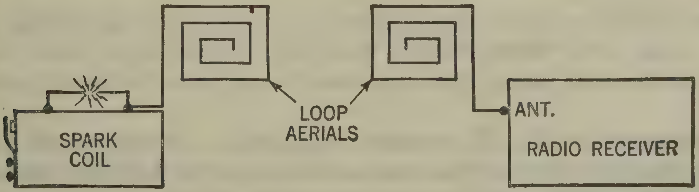
Demonstration 1: Light a carbon-vacuum electric bulb. Note that heat and light waves pass through the vacuum.

Demonstration 2: Demonstrate the apparatus shown in Figure 9.

Demonstration 3: Obtain a number of soft iron rods about $\frac{1}{4}$ in. in diameter and 12 in. long. Make a bundle of them about $1\frac{1}{2}$ in. in diameter. Wrap a layer of tape over them. Wind upon this core about 3 lbs. of bell wire (No. 18 double cotton covered) making a winding about 6 in. wide. Attach the ends of this coil to the 110-volt alternating-current line. Wind another coil of bell wire consisting of about 30 turns having a diameter of 2 in. Attach a telephone receiver to the ends of this coil. Slip the small coil over the iron core. Note the pickup of the 60-cycle note. Move the small coil further and further away from the large coil. Note that the note falls off.

Chapter 4

Demonstration 1: *To show the need for an aerial.* Set up the following apparatus:



The loop aerials or antennas may be made by winding about 15 turns of bell wire on dowel sticks, spacing the turns about 1 in. apart. Place the spark coil in a felt-lined box to absorb the spark noise. The radio receiver will pick up the spark over a fairly large distance.

Disconnect the transmitting antenna. Note that the pickup drops off. Disconnect the receiving antenna. The pickup drops off still more and disappears.

Demonstration 2: *To illustrate the natural period of a wave or vibration.*

(a) Suspend two pendulums, one 2 ft. long and the other 3 ft. long. Count the number of swings of each in one minute.

(b) Strike various tuning forks of different sizes. Note the different notes characteristic of each fork.

Demonstration 3: *To demonstrate the principle of tuning.* Obtain four tuning blocks having the following frequencies: two of 512 vibrations per second and two of 256 vibrations per second. Strike one 512-v.p.s. block. Note that only the other 512-v.p.s. block picks up the vibrations. Then strike one 256-v.p.s. block. Only the other 256-v.p.s. block will pick up these vibrations.

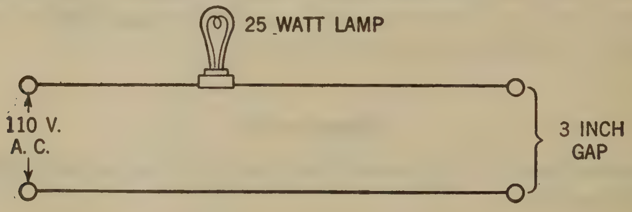
Demonstration 4: Demonstrate the apparatus shown in Figure 11 to show how the reproducer changes fluctuating electrical currents into sound.

Demonstration 5: *To show how the detector works.* Connect up a crystal receiver as shown in Figure 22. Short out the crystal. Note how the signal disappears.

Chapter 5

Demonstration 1: *To illustrate the behavior of conductors and insulators.*

Arrange the following circuit:



Across the gap in the circuit place in turn rods of the following materials: glass, iron, brass, copper, porcelain, carbon, zinc, wood, and the like. The 25-watt lamp lights up when a conductor is placed across the gap.

Demonstration 2: *To construct an aerial.* If the school building is not of the steel-frame type, run a 50-ft. piece of bell wire around the molding of the room. Another method of construction is to run a 100-ft. length of bell wire from the window to a nearby tree or flag pole. Failing either of these possibilities, the wire may be dropped out the window and permitted to hang down, or else run up the side of the building to the roof. Care should be taken that the bare end of the wire does not touch the ground or the side of the building.

Chapter 6

Demonstration 1: Show the students various tuning coils from commercial receivers, explaining methods of connecting the windings into the circuit.

Demonstration 2: (a) Open up various fixed condensers and show their construction. Show the ratings on these condensers.

(b) Show various variable tuning condensers. Point out the rotor and stator plates and show their connections.

Demonstration 3: Repeat Demonstration 3, Chapter 4.

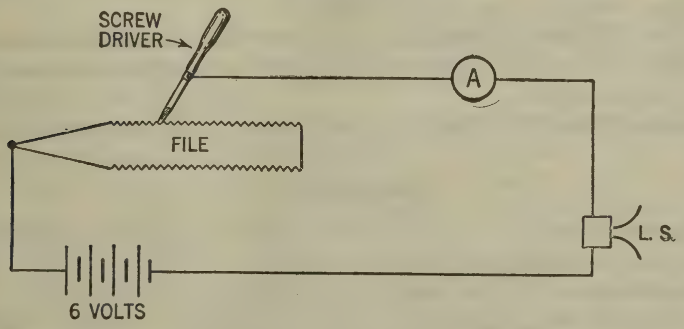
Demonstration 4: *To exhibit a mechanical analogy of the fact that for resonance or tuning the transmitter and receiver need not be physically the same.* Take two tuning forks mounted on resonance boxes, one of 320 vibrations per second and the other of 384 vibrations per second. Strike one and show that there is no resonance. Then load one or more pinch clamps on the 384-v.p.s. fork. By trial and error find the condition where striking the 320-v.p.s. fork results in resonance with the 384-v.p.s. fork and its load.

Chapter 7

Demonstration 1: Perform the experiment described in Figure 14.

Demonstration 2: Demonstrate the construction of a telephone receiver, of a pair of earphones, and of a magnetic loudspeaker.

Demonstration 3: *To show that a reproducer will respond to a varying but not a steady current.* Connect a battery, an ammeter, a magnetic loudspeaker, a file, and a screwdriver as follows:



When the screwdriver is in resting contact with the file, a steady current flows through the ammeter, but no sound results. But as the screwdriver slides over the file a fluctuating current flows through the ammeter and a sound is heard coming from the loudspeaker.

Chapter 8

Demonstration 1: Show the students various crystals, of fixed and adjustable type.

Demonstration 2: Connect a crystal detector, 1,000-ohm resistor, a single dry cell, and a sensitive milliammeter in series. Record the milliammeter reading. Now reverse the dry cell. Compare the milliammeter reading with the previous recording.

Demonstration 3: Construct the crystal set shown in Figure 22.

Chapter 9

Demonstration 1: Show a barograph chart and explain it.

Demonstration 2: Construct a graph on the basis of the time it takes the students to work five problems.

Demonstration 3: If a cathode-ray oscillograph is available, show an alternating-current sine curve, a direct-current voltage, and an audio-frequency (voice) wave. Interpret them.

Chapter 10

Demonstration 1: On a large nail wind a coil of bell wire consisting of about 25 turns (primary). To the ends of this coil connect a key and dry cell in series. On the same nail wind a second coil (secondary) of the same number of turns. Connect a galvanometer to the ends of this coil. Closing the key of the primary coil will send a current flowing in the secondary coil (as shown by the deflection of the galvanometer).

Demonstration 2: *To demonstrate a step-down transformer.* Obtain a bell transformer. Place 110 volts of alternating current on the primary. Attach an electric bell to the secondary.

Demonstration 3: *To demonstrate a step-up transformer.*

(a) Place 6 volts on the primary of a spark coil and notice the high-voltage spark across the secondary.

(b) Put 110 volts alternating current on the primary of a neon-sign transformer. Note the high-voltage spark across the secondary (from 5,000 to 15,000 volts).

Demonstration 4: Construct set shown in Figure 40.

Chapter 11

Demonstration 1: Cut an old dry cell in half. Point out the carbon rod, the zinc shell, and the electrolyte.

Demonstration 2: *To study the law of electric charges.*

(a) Suspend two pith balls from silk strings. Charge them both negatively by touching each with a hard rubber rod that has been stroked on a piece of fur. Now bring the two pith balls near each other. They repel each other.

(b) Charge one pith ball negatively as above. Charge the other positively by touching it to a glass rod that has been rubbed on silk. Now bring the two pith balls near each other. They attract each other.

Demonstration 3: *To distinguish between alternating current and direct current.* Connect a dry cell to a center-zero ammeter through a 30-ohm resistor. The needle moves to one side and remains stationary.

Now replace the dry cell with a magneto or a Brownlee generator connected for alternating current. Slowly rotate the handle and note how the needle of the meter fluctuates to either side of the center zero.

Chapter 12

Demonstration 1: Inspect the structure of a Leyden jar. Charge it up with an electrostatic machine. Then show the spark as it is discharged with a pair of discharging tongs.

Demonstration 2: Connect a 90-volt battery across a 1-μfd. condenser. Disconnect and discharge with a piece of wire, showing the spark.

Demonstration 3: *To exhibit an analogy to the oscillatory discharge of a condenser.* Suspend a ball from a string about a yard long. Raise the ball to one side and release it. Note that the ball overshoots the center position and swings to the opposite side. Note how long it takes the ball to come to rest.

Demonstration 4: *To note the effect of self-inductance.* Connect a 90-volt battery in series with a 30-henry choke and a key switch. Close the switch. Now open it and note the spark that jumps across the gap, indicating that current is still flowing for an instant after the key switch is opened.

Chapter 13

Demonstration 1: Arrange electric light bulbs in series and parallel circuits and trace the paths of current flow for the students.

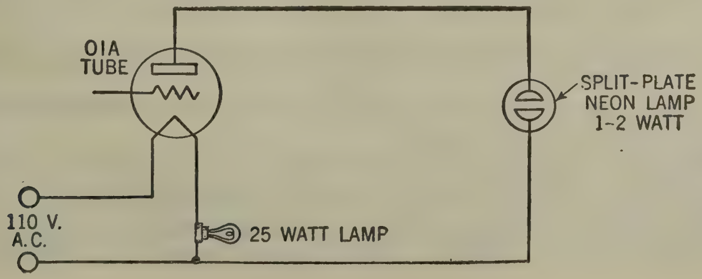
Demonstration 2: Repeat Demonstration 4, Chapter 10, placing a .006-μfd. condenser across the phones.

Chapter 14

Demonstration 1: Demonstrate the apparatus shown in Figure 56. The tube may be any triode with the grid left free. The meter should be an 0-100 microammeter.

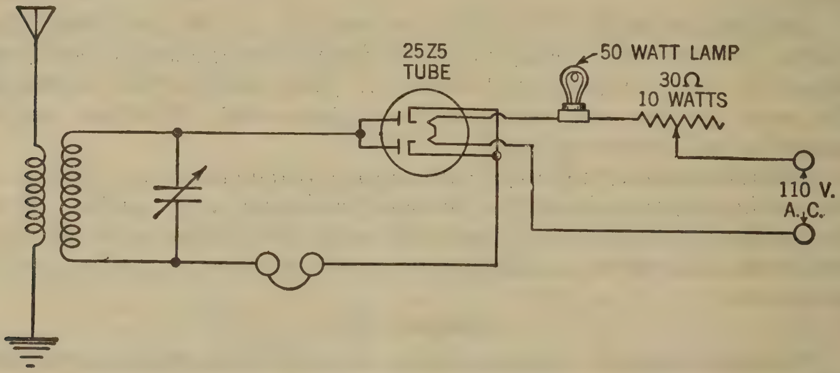
Demonstration 2: Demonstrate the apparatus shown in Figures 57, 58, and 59. The tube may be a type 01A with the grid left free. The meter should be 0–10 milliammeter. The B battery should be from 45 to 90 volts. A small hand magneto, turned slowly, will give the alternating-current voltage.

Demonstration 3: *To show how the diode acts as a rectifier.* Arrange the following apparatus:



Place the neon lamp in a 110-volt alternating-current socket. Show how both plates are illuminated. Set the neon lamp in a 110-volt direct-current socket. Show that only one plate (the negative) is illuminated. The 25-watt lamp is merely a dropping resistor to reduce the 110 volts to a value suitable for lighting the 01A tube filament. Now attach apparatus to the 110-volt alternating-current line. Only one of the neon plates lights up, showing that the alternating current has been rectified to direct current by the diode.

Demonstration 4: *To exhibit a working diode detector.* Set up the following apparatus:



The tuner is the one shown in Figure 40 except that the crystal detector has been replaced by a diode (the 25Z5 tube). The 50-watt lamp and the 30-ohm 10-watt rheostat are used to drop the 110-volt line current to the proper value to operate the filament of the tube. The rheostat must be carefully adjusted for proper results.

If desired, the 25Z5 tube may be replaced by a 6H6 tube operating from a 6-volt source. The 50-watt lamp must then be omitted.

Chapter 15

Demonstration 1: *To show how the grid voltage controls plate current.* In the set-up of Demonstration 3, Chapter 14, connect a dry cell between the grid and the filament so as to place a positive charge on the grid. Attach more and more cells in series so as to make the grid more and more positive. Note how the plate of the neon lamp glows brighter and brighter, indicating more plate current. Now reverse the cells to place a negative charge on the grid. Note how the brightness of the plate of the neon lamp diminishes and disappears when the grid becomes negative enough.

Demonstration 2: *To compare control of plate current by the plate voltage and by the grid voltage.* Hook up apparatus as shown in Figure 64. The tube may be a type 30. The filament may be lighted by a single dry cell. The B battery is 90 volts and should be variable. The meter is a direct-current 0–10 milliammeter. Place the charges on the grid by connecting dry cells between the grid and the filament. Vary the grid charges and note the change in plate current for every volt change in grid voltage.

Keep the grid voltage constant and vary the plate voltage. Note the change in plate current for every volt change in plate voltage. Compare the effect on the plate current of the grid voltage and plate voltage. Make graphs.

Demonstration 3: Construct the receiver shown in Figure 73. Keep all leads as short as possible. Tune in a station. Remove the grid condenser. Note the effect. Replace the grid condenser and remove the grid leak. Note the effect.

Demonstration 4: *To study how a filament rheostat acts as a volume control.* Repeat Demonstration 2, Chapter 15, but include a 30-ohm rheostat in series with the filament and the A battery. Study the effect of changes in rheostat settings upon the plate current.

Chapter 16

Demonstration 1: *To show how a varying direct current may operate a transformer.* Obtain a 1:1 or 1:2 audio-frequency transformer. Connect the primary in series with a 6-volt battery and a 30-ohm rheostat. Connect the secondary to a center-zero voltmeter. Move the rheostat arm back and forth and note the variations on the voltmeter. Note that the voltage output of the secondary is alternating in character. Also note that when there is no current variation in the primary, no voltage is produced across the secondary.

Demonstration 2: Repeat Demonstration 3, Chapter 3, holding the smaller coil with its axis the same as the large coil and then with its axis at right angles to the large coil. Note difference.

Demonstration 3: Build the regenerative receiver shown in Figure 76. It may be necessary to reverse the tickler-coil terminals if the set fails to operate.

Chapter 17

Demonstration 1: Construct the set shown in Figure 92. Short out the C battery to show why the grid bias is necessary.

Demonstration 2: Build a public-address system as shown in Figure 93.

Demonstration 3: Build an electrical phonograph as shown in Figure 94.

Demonstration 4: *To study an analogy of the carbon microphone.* Cut into five pieces the carbon of a dry cell. Line them up in a grooved board. Connect the original ends of the carbon in series with a 6-volt battery and a 6-volt 15-watt lamp. Squeeze the carbon pieces together firmly and note the brilliance of the light. Slowly relax the compression and note how the intensity drops off.

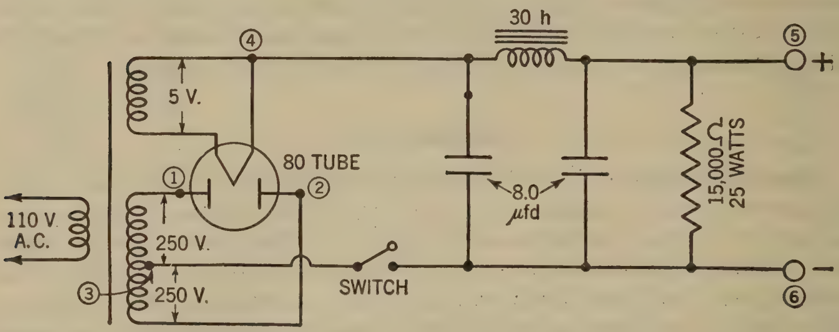
Chapter 18

Demonstration 1: *To show how a tube acts as a rectifier.* Repeat Demonstration 3, Chapter 14.

Demonstration 2: *To explain the component parts of a power transformer.* Repeat Demonstrations 2 and 3, Chapter 10.

Demonstration 3: *To demonstrate the principle of a voltage divider.* Connect a 500-ohm potentiometer in series with a 90-volt battery. Connect a direct-current 0–100 voltmeter to one end of the potentiometer and to the sliding arm. Move the sliding arm across the potentiometer and note how the reading of the voltmeter varies.

Demonstration 4: Construct the following apparatus:



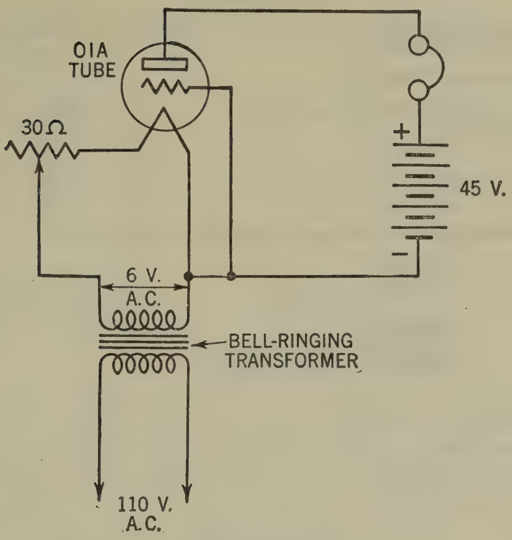
The power transformer should be able to deliver about 250 volts on either side of the center tap. The rectifier tube is a type 80. The filter condensers are 8.0 μfd. at 450 volts direct current working voltage. The choke is an ordinary 30-henry choke coil. The voltage divider is 15,000 ohms rated at 25 watts. Connect a 2-watt split-plate neon lamp in series with a magnetic speaker and test as follows:

1. Open switch. (a) Test from point 3 to point 1. Both plates light up, indicating alternating current. 60-cycle hum is heard in the loudspeaker. (b) Test from point 3 to point 2. Both plates light up, as above. (c) Test from point 3 to point 4. One plate lights, indicating direct current. 60-cycle hum is heard in the loudspeaker.
2. Close switch. (a) Test from point 5 to point 6. One plate lights, indicating direct current. No hum is heard in the loudspeaker.

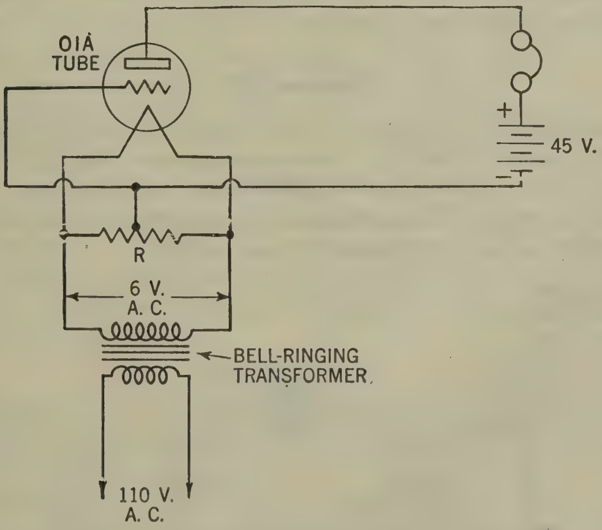
Demonstration 5: Repeat above with a cathode-ray oscillograph.

Chapter 19

Demonstration 1: Hook up the apparatus in the upper illustration, page 309. Note the 60-cycle hum in the earphones.

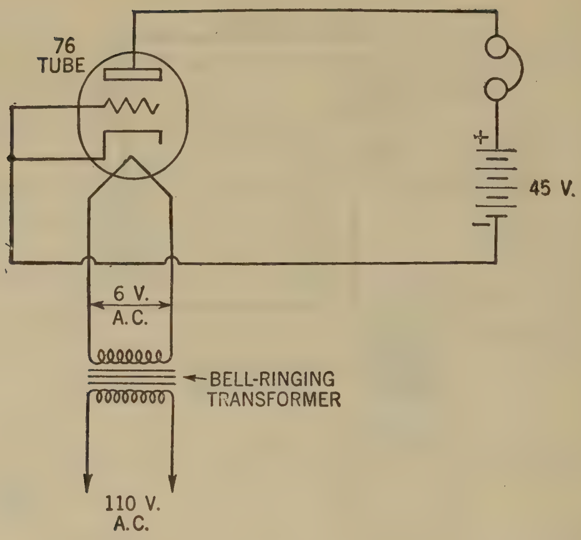


Demonstration 2: Hook up the following apparatus:



R is a 20 to 40 ohm center-tapped resistor. The hum is nearly gone.

Demonstration 3: Hook up the following apparatus. The hum disappears.

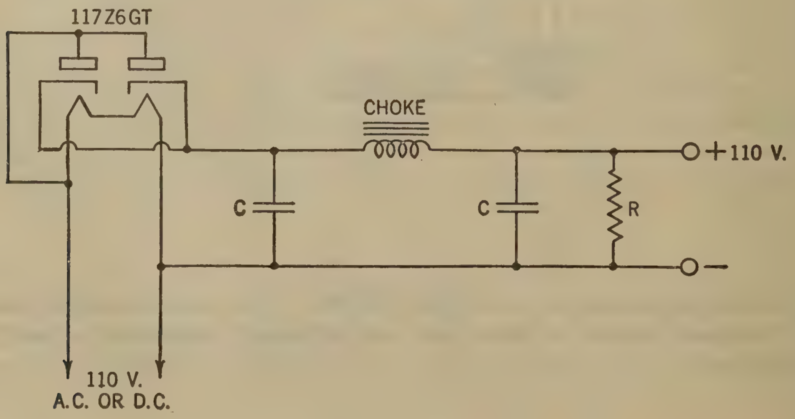


Chapter 20

Demonstration 1: Repeat Demonstration 3, Chapter 18, using a center-zero voltmeter. Leave the slider arm of the potentiometer in one position and switch the other lead of the voltmeter from one end of the potentiometer to the other. Note that one side of the potentiometer is negative and the other is positive.

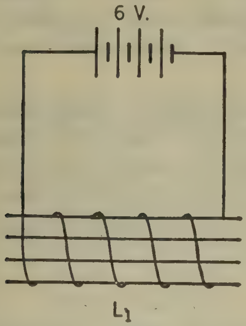
Chapter 21

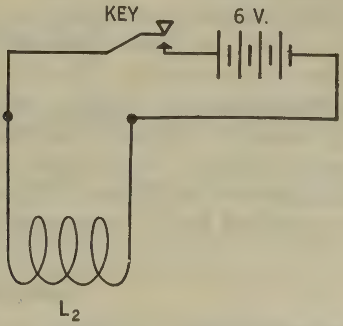
Demonstration 1: Construct the below A.C.-D.C. power supply. The tube is a type 117Z6GT. The condensers are 12-μfd. 150-volt working voltage. The resistor is of 10,000 ohms and 25 watts. The choke coil is of 15 henries. When using on direct current reverse the plug to the wall outlet if the power supply fails to work.



Chapter 22

Demonstration 1: Construct the following apparatus:





L_1 corresponds to the field coil of the dynamic speaker. It consists of about 300 turns of bell wire wound on a soft iron core and it is held in a fixed position. L_2 corresponds to the voice coil of the dynamic speaker. It consists of about 30 turns, air wound, with a diameter of about 1 in. It is suspended so that it is free to move.

Close the key. The voice coil moves violently.

Demonstration 2: Obtain an old electromagnetic dynamic speaker. Open it up to show the field coil, voice coil, and spider.

Chapter 23

Demonstration 1: Examine a three-gang variable condenser. Notice how each condenser moves an equal amount with the rotation of the shaft. Examine the trimmer on each condenser.

Demonstration 2: Construct the tuned radio-frequency receiver shown in Figure 139.

Chapter 24

Demonstration 1: Repeat Demonstration 4, Chapter 15.

Demonstration 2: Replace the 2,000-ohm grid-bias resistor in the second radio-frequency stage in the set shown in Figure 139 by a 5,000-ohm rheostat. Note the effect on the volume of the set at different settings of this rheostat.

Chapter 25

Demonstration 1: *To show that different sounds may have different pitches.* Strike different types and shapes of materials and note the pitch of each sound produced.

Demonstration 2: *To show how mechanical filters may remove high or low tones.* Talk through a cardboard tube, a megaphone, the cupped hands, and the like.

Demonstration 3: *To show how sounds of different pitches may produce currents of different frequencies.* Connect a telephone receiver to a cathode-ray oscillograph. Talk into the receiver and notice the wave picture.

Chapter 26

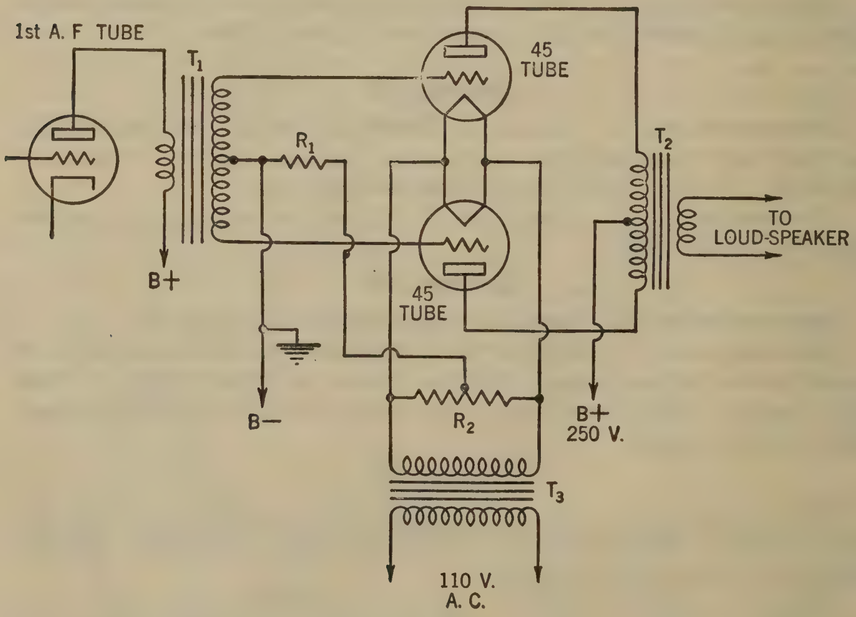
Demonstration 1: *To show the principle of beats.* Obtain two tuning forks whose frequencies are close together (such as 320 vibrations per second and 384 vibrations per second). Strike both and hold them close to each other. Note the beats.

Demonstration 2: Operate ordinary radio receiver. Near-by, operate a regenerative receiver as shown in Figure 76. Tune both receivers to the same station. Now adjust the regenerative control until the regenerative receiver oscillates. The second receiver will pick up the radio wave transmitted by the regenerative receiver as a squeal or whistle.

Chapter 27

Demonstration 1: Obtain as many different types of burnt-out tubes as possible. Break the glass envelopes and study the electrodes.

Demonstration 2: Build this push-pull audio-frequency amplifier: T_1 is a push-pull input transformer; T_2 is a push-pull output transformer; T_3 is a 2.5-volt filament transformer; R_1 is 400-ohm, 5 watts; R_2 is a 20- to 40-ohm center-tapped resistor; the power tubes are type 45.



Chapter 28

Demonstration 1: *To show the directional property of a loop aerial.* Obtain a portable radio receiver with a built-in loop aerial. Tune in a station. Rotate the receiver. Note how the station dies away and comes in again as the set is rotated.

Appendix

THE EVENTFUL DATES IN RADIO DEVELOPMENT

1727 Cuneus and Musschenbroek (Dutch) discovered the principle of the condenser.

1842 Joseph Henry (U. S.) experimented with induced voltages.

1850 Faraday (English) performed experiments similar to those of Joseph Henry.

1867 Clerk Maxwell (Scotch) showed mathematically that light is an electromagnetic wave and predicted that there must be other electromagnetic waves of different frequencies.

1874 Ferdinand Braun (German) discovered the rectifying action of some crystals.

1879 Hughes (English) heard wireless waves but could not explain them to the Royal Society.

1884 Edison (U. S.) observed the "Edison effect."

1887-9 Heinrich Hertz (German) developed a spark transmitter using a condenser with plates fairly wide apart. He developed the first wireless detector.

1889 Sir Oliver Lodge (English) developed the principle of tuning based on the previous work of Michael Pupin (American).

1890 Branly (French) developed the Branly coherer, a form of detector, based on the earlier work of Guitard (French).

1894 Marconi (Italian) developed an aerial and ground system, using the Branly coherer. He radiotelegraphed over a distance of two miles.

1902 Fessenden (U. S.) developed the continuous-wave system with radio-frequency alternators. Poulsen (Denmark) worked out another continuous wave system with an arc.

1901 Marconi sent a signal from England to Newfoundland, using a detector invented by Lieutenant Solari (Italian).

1904 J. A. Fleming (English) developed the Fleming valve.

1906 General Dunwoody (American) devised a crystal detector.

1907 Lee De Forest (U. S.) developed the triode with a control grid.

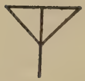
1907 E. H. Armstrong (U. S.) developed the regeneration principle for receivers and transmitters.

1909 The steamship *Republic* sank, January 23. People were rescued for the first time because of radio. Radio was popularized.

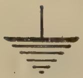
Recent Hazeltine (U. S.) developed the neutrodyne receiver.

Recent Armstrong (U. S.) developed the superheterodyne and frequency-modulation receiver.

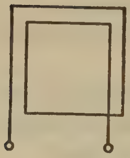
SCHEMATIC SYMBOLS USED IN CIRCUIT DIAGRAMS



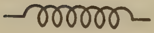
Antenna



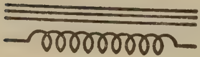
Ground



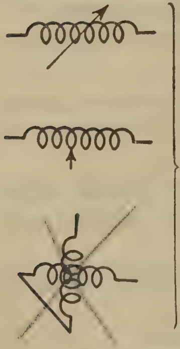
Loop
Aerial



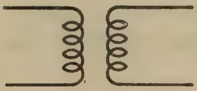
Air-core
Inductance



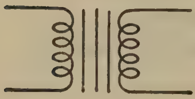
Iron-core
Inductance



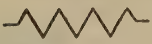
Variable
Inductance



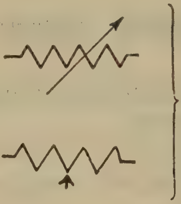
Air-core
Transformer



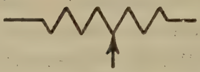
Iron-core
Transformer



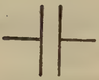
Resistor



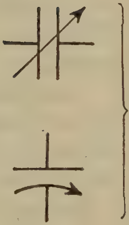
Variable
Resistor
(Rheostat)



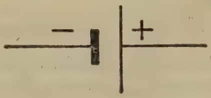
Variable
Resistor
(Potentiometer)



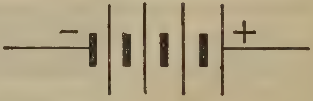
Fixed Condenser



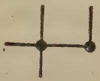
Variable
Condenser



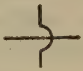
Single Cell



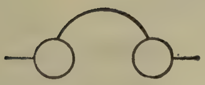
Battery



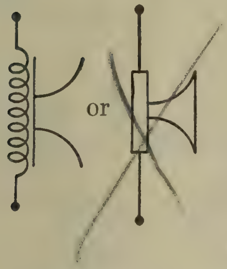
Wires Connected



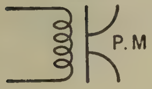
Wires Not Connected



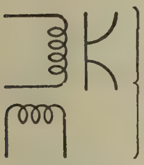
Headphones



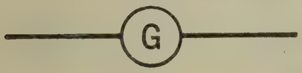
Loudspeaker



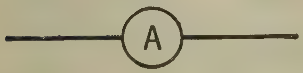
Permanent-magnet
Dynamic Speaker



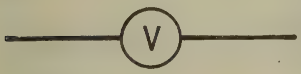
Electromagnetic
Dynamic Speaker



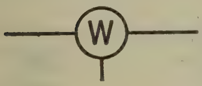
Galvanometer



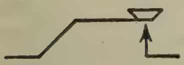
Ammeter



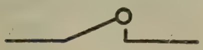
Voltmeter



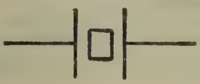
Wattmeter



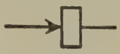
Key



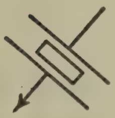
Switch



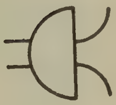
Crystal



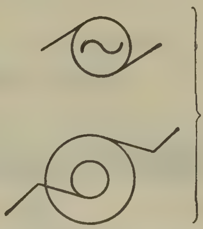
Crystal Rectifier



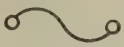
Crystal Pickup



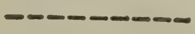
Microphone



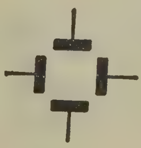
A. C.
Generator



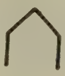
Fuse



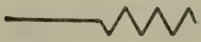
Shielding



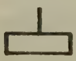
Cathode-ray Tube
Deflecting plates



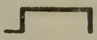
Tube filament



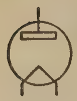
Tube grid



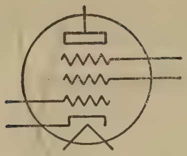
Tube plate



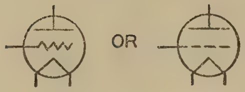
Tube cathode



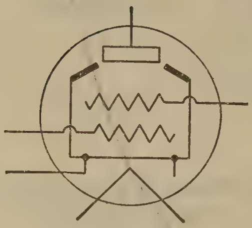
Diode



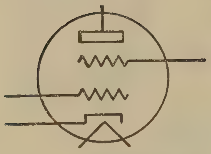
Pentode



Triode



Beam-
Power
Tube



Tetrode

ABBREVIATIONS AND SYMBOLS

Alternating current	A.C.
Ampere	a., amp.
Amplitude modulation	A.M.
Antenna	Ant.
Audio frequency	A.F.
Automatic volume control	A.V.C.
Beat frequency	B.F.
Beat-frequency oscillator	B.F.O.
Capacitance	C
Capacitive reactance	X_C
Cathode ray	c.r.
Centimeter	cm.
Continuous waves	C.W.
Crystal	Xtal.
Current	I
Cycles per second	c.p.s.
Direct current	D.C.
Electromotive force	E.M.F.
Farad	fd.
Frequency	f
Frequency modulation	F.M.
Ground	gnd.
Henry	h
High frequency	H.F.
Impedance	Z
Inductance	L
Inductive reactance	X_L
Intermediate frequency	I.F.
Interrupted continuous waves	I.C.W.
Kilocycles (per second)	kc.
Kilowatt	kw.
Mega (million)	M or m
Megacycles (per second)	Mc. or mc.
Megohm	MΩ or ω
Meter (measure of length)	m.
Micro $\frac{1}{1,000,000}$	μ
Microampere	μa. or μamp.
Microfarad	μfd.
Microhenry	μh.
Micromicro $\frac{1}{1,000,000,000,000}$	$\mu\mu$
Micromicrofarad	$\mu\mu$fd.
Microvolt	μvolt
Microwatt	μw.
Milli $\frac{1}{1,000}$	m
Milliampere	ma.
Millihenry	mh.
Millivolt	mv.
Milliwatt	mw.
Modulated continuous waves	M.C.W.
Ohm	Ω

ABBREVIATIONS AND SYMBOLS—Continued

Power	*P*	Tuned radio frequency	T.R.F.
Power factor	p.f.	Ultrahigh frequency	U.H.F.
Radio frequency	R.F.	Volt	v.
Resistance	*R*	Watt	w.

ELECTRICAL UNITS

Capacitance	farad	Phase	degree
Capacitive reactance	ohm	Power	watt
Current	ampere	Resistance	ohm
Frequency	cycles per second	Voltage (potential difference, E.M.F.)	volt
Impedance	ohm	Wave length	meter
Inductance	henry		
Inductive reactance	ohm		

R.M.A. COLOR CODE

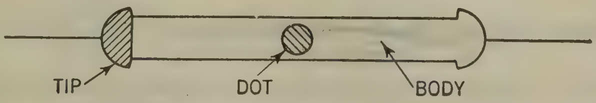
To identify the various connections and values of standard radio components, the Radio Manufacturers Association (R.M.A.) has adopted a color code.

R.M.A. Color Code for Resistors

Numbers are represented by the following colors:

0 — black
1 — brown
2 — red
3 — orange
4 — yellow
5 — green
6 — blue
7 — violet
8 — gray
9 — white

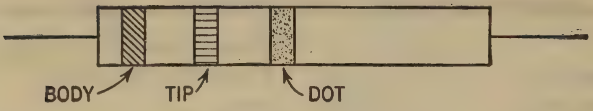
Three colors are used on each resistor to identify its value. The *body* color represents the first figure of the resistance value. One *end* or *tip* is colored to represent the second figure. A colored *band* or *dot* near the center of the resistor gives the number of zeros following the first two figures.



Here is an example. Assume a resistor whose body is yellow, tip blue, and dot red. We thus get yellow, blue, red—which, translated into the code, stands for

4 — 6 — 00 or 4600 ohms.

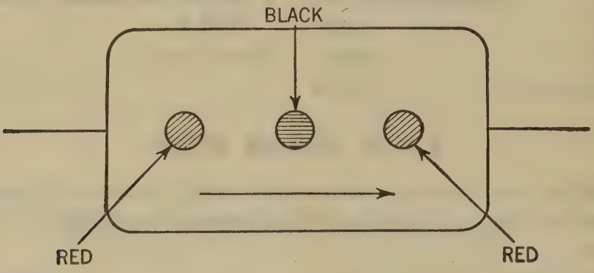
Some resistors are marked with three bands of color. The band nearest the end is the body color, the next band the tip color and the third band is the dot color.



R.M.A. Color Code for Condensers

Small mica condensers may be marked with three color dots, with an arrow or other symbol indicating the sequence of numbers. The color code is the same as for resistors except that the readings are in micromicrofarads instead of ohms.

Thus, if the condenser were marked as follows:



the value of this condenser would be:

2 — 0 — 00 or 2,000 $\mu\mu$fd. (.002 μfd.)

R.M.A. Color Code for Power Transformers

To identify the various leads the following color code has been adopted:

1. Primary leads—black. If tapped: common—black; tap—black and yellow striped; finish—black and red striped.
2. High-voltage plate winding—red. Center tap—red and yellow striped.
3. Rectifier filament winding—yellow. Center tap—yellow and blue striped.
4. Filament winding No. 1—green. Center tap—green and yellow striped.
5. Filament winding No. 2—brown. Center tap—brown and yellow striped.
6. Filament winding No. 3—slate. Center tap—slate and yellow striped.

R.M.A. Color Code for Audio-frequency Transformers

Blue—Plate (finish) lead of the primary.

Red—B+ lead (this applies whether the primary is plain or center tapped.)

Brown—Plate (start) lead on center-tapped primaries. (Blue may be used for this lead if polarity is not important.)

Green—Grid (finish) lead of secondary.
Black—Grid return (this applies whether the secondary is plain or center tapped).
Yellow—Grid (start) lead on center-tapped secondaries. (Green may be used for this lead if polarity is not important.)

Note: These markings apply also to line-to-grid, and tube-to-line transformers.

R.M.A. Color Code for Intermediate-frequency Transformers

Blue—Plate lead.
Red—B+ lead.
Green—Grid (or diode) lead.
Black—Grid (or diode) return.

Note: If the secondary of the intermediate-frequency transformer is center-tapped, the second diode plate lead is green and black striped, and black is used for the center-tap lead.

R.M.A. Color Code for Loudspeaker Voice Coils

Green—finish   Black—start

R.M.A. Color Code for Loudspeaker Field Coils

Black and red striped—start
Yellow and red striped—finish
Slate and red striped—tap (if any)

WAVE-LENGTH–FREQUENCY CONVERSIONS

$$\text{wave length (in meters)} = \frac{300{,}000{,}000}{\text{frequency (in cycles per second)}}$$

Station	Location	Frequency (cycles per second)	Wave length (meters)
WSYR	Syracuse	570,000	526
WEAF	New York	660,000	454.3
KPO	San Francisco	680,000	440.9
WGN	Chicago	720,000	416.4
WJR	Detroit	760,000	394.5
WCCO	Minneapolis	830,000	361.2
WWL	New Orleans	870,000	344.6
KHJ	Los Angeles	930,000	322.4
WAAT	Jersey City	970,000	309.1
KJR	Seattle	1,000,000	299.8
WHO	Des Moines	1,040,000	288.3
WBAL	Baltimore	1,090,000	275.1
KSL	Salt Lake City	1,160,000	258.5
WOAI	San Antonio	1,200,000	249.9
WLAC	Nashville	1,510,000	199.1

velocity of a radio wave = 300,000,000 meters per second

The Resonant Wave Length

$$\text{wave length (in meters)} = 1{,}885\sqrt{L \times C}$$

L is in microhenries; C is in microfarads.

INTERNATIONAL MORSE CODE TABLE

A •—
B —•••
C —•—•
D —••
E •
F ••—•
G ——•
H ••••
I ••

J •———
K —•—
L •—••
M ——
N —•
O ———
P •——•
Q ——•—
R •—•

S •••
T —
U ••—
V •••—
W •——
X —••—
Y —•——
Z ——••

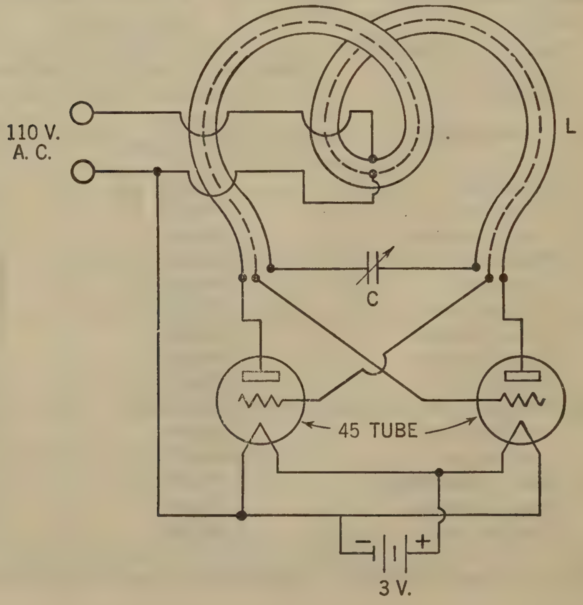
1 •————
2 ••———
3 •••——
4. ••••—
5 •••••

6 —••••
7 ——•••
8 ———••
9 ————•
0 —————

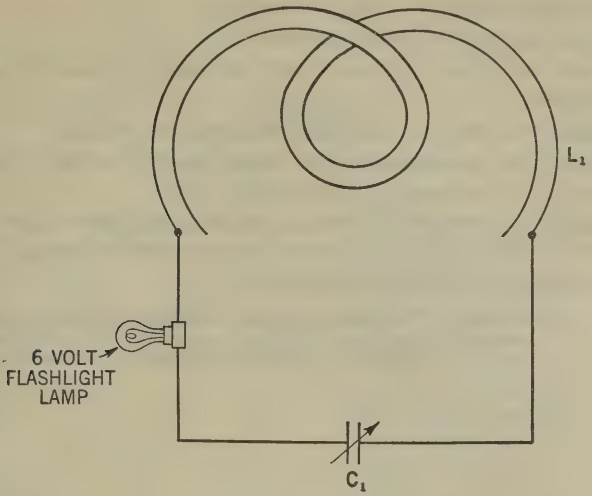
Period •—•—•—
Interrogation ••——••
Break —•••—

Wait •—•••
End of message •—•—•
End of transmission •••—•—

Construction of an Oscillator and Wavemeter



C is a 140 $\mu\mu$fd. variable condenser. L is 3 turns $\frac{1}{8}$-in. copper tubing, 3 in. in diameter. An insulated wire runs through the tubing and is connected to the grids of the tubes. L_1 is the same as L, except that there is no wire running through the tubing. C_1 is the same as C.



When the oscillator is connected up, bring the wavemeter close so that the plane of L_1 is parallel to that of L. Then turn C_1 slowly until the flashlight lamp lights up. The wavemeter is now in resonance with the oscillator. Change C to vary the frequency of the oscillator. The flashlight lamp goes out and C_1 must be adjusted again before the lamp lights up again.

HOW TO SOLDER

There are three essentials to successful soldering: cleanliness, flux, and heat.

1. *Cleanliness.* Be sure that the surfaces to be soldered are perfectly clean. Scrape the surfaces with a knife or rub with sandpaper or steel wool wherever possible.
2. *Flux.* Use a rosin flux. An acid flux may corrode the wires. Use flux sparingly, enough to flow thinly over the surfaces, not to drown them. After soldering, wipe off any excess flux.
3. *Heat.* Heat the surfaces to be soldered until the solder flows over them. If possible, keep the hot iron on the joint even after the solder has flowed so as to be sure there is enough heat. For ordinary radio work a 65- to 75-watt soldering iron is sufficient. Greater soldered surfaces require greater heat.
4. Keep the soldering iron clean by removing any oxide that may form on it. Tin the iron by scraping it clean, dipping the point into the flux and then applying solder to the tip.

PRACTICAL DATA

1. Make connections as short as possible.

2. Shield as many grid leads as you can.

3. The rotor of a variable condenser is usually grounded to eliminate body capacitance.

4. Pushback wire will be found convenient for wiring.

5. In electrolytic condensers, the black wire is usually the negative wire, and the red wire usually the positive wire.

6. For shielding purposes, in using paper condensers, the end which is marked by a black band is usually the grounded or negative end.

7. To calculate a line-cord resistance:

$$R \text{ (ohms)} = \frac{110 - \text{sum of all the filament voltages of the tubes in series}}{\text{current through the tube filaments}}$$

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